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EDITORIAL

Two of the articles in this issue deal with different aspects of a neglected problem in agricultural administration—that of obtaining reliable information on a national scale as a basis for research and development work. This need faces those in authority when they have to assess the value to a community of a promising treatment or determine which of several problems is important enough to merit intensive research. It is a perennial and a vital need. Without the requisite information it is neither possible to gain the full benefits from past work nor to direct fresh investigations to the greatest practical advantage. The matter is clearly one of consequence, and, as the wanted facts are not difficult to obtain by survey work and field experiments, it is surprising that a problem should exist. Yet these measures are seldom taken on a large enough scale, and progress is slower than it otherwise could be.

Statistics on Animal Health

Except for the facts now being revealed by the survey work described in these pages there is very little accurate information on the incidence of diseases of farm animals for the U.K. as a whole. Data from past investigations are now largely out of date. It has already been shown in this journal (1: 32-3) that advances in veterinary medicine resulting in better control of disease have greatly altered the clinical picture. Such scourges as tuberculosis, contagious abortion and streptococcal mastitis have been greatly reduced in incidence, and the general effect is apparent to every dairy farmer. Before the war not less than half the cows passing out of our dairy herds were disposed of owing to disease and the average cow had a milking life of three lactations; today, owing to the rapid progress of attestation and improved general health, the average life of a dairy cow in tuberculosis-free areas—which now contain half of our milking animals—is five lactations, though elsewhere it is still three to four. But with the decline of controllable diseases others have come to the fore, notably staphylococcal mastitis, infertility associated with *Vibrio foetus*, and metabolic disorders; and only by the regular collection of disease statistics over a wide area is it possible to indicate the relative importance of the problems that need special investigation and the progress made with others.

It is to be hoped that survey work on disease incidence will be extended to other classes of live-

stock and that the economic aspect will not be neglected. The extent of losses in produce or cash is the final measure of the size of a problem, and the administrator must have this information to enable him to determine the degree of priority a project should receive in his scheme of things and to allocate the necessary resources. Should remedial measures already be available, he will also want arguments to hand with which to convince farmers of the advantages of treatment. There is an astonishing dearth of statistics of this kind, especially on the more insidious infections. Next to nothing is known, for instance, about the losses caused by Johne's disease and nutritional disorders like acetonemia and bloat, which are known to be widespread in Britain and matters of increasing veterinary concern.

Sub-clinical Effects of Worms

If the various causes of animal ill health could be assessed on a world basis in order of their practical importance, nematode worms would assuredly come near the top of the list. They are prevalent everywhere and affect all kinds of livestock, being most serious in sheep and pigs. In the U.S.A. worm parasites are held responsible for about three-quarters of the total losses attributable to ill health in sheep, and although adequate figures are not available for the U.K. it may be said without fear of contradiction that worms cost our sheep industry more than all other veterinary troubles of sheep put together. Clearly, worms are far from being controlled in practice, despite the efficacy of anthelmintics against most of the species concerned. Dr. Spedding's work on the subject is enlightening. When sheep are obviously suffering from worms, much damage has already been done. Indeed, the effects of infestation are the same as those caused by poor nutrition, and considerable loss of flesh and wool may occur before the trouble is detected—and it may never reach the stage of diagnosis. For this reason both grazing management and strategic dosing with anthelmintics are essential in control.

Sub-clinical effects of this kind apply to other parasites and diseases, and they become more important as control measures improve in efficacy. On economic as well as on technical grounds they call for more attention than they have hitherto received and, in particular, for research into better methods of diagnosis of infections that give little or no clinical sign of their presence.

FIELD EXPERIMENT PROGRAMMES

H. L. Richardson

It frequently happens that an agricultural treatment of great potential benefit to a nation is not generally adopted because steps were not taken to obtain the information needed to make sound recommendations to farmers. Only field experiments on a large scale can provide this. Experience with fertilizers shows that few countries lack the resources for this work, and the total cost is negligible in comparison with the national gains.

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When governments or other major organizations have to make policy decisions or plan developments on the basis of the effects of agricultural treatments, large and carefully planned programmes of field experiments will give reliable information that can be obtained in no other way. It is true that where a sufficiently large number of even ill-assorted trials has been done in the past the results may be brought together and be of value after statistical treatment: a classical example of this is the paper by Crowther and Yates [10], which was employed as a basis for fertilizer rationing in the United Kingdom during the war. But many countries lack the experiments, and past work may not solve modern problems. There are also questions that have not previously been studied, such as the introduction of a new kind of pesticide or fertilizer or a new or modified agricultural system. It is not enough to guess at the answer from experience in other countries or to do a few casual trials. An extensive programme of well-designed experiments is essential.

THE IMPORTANCE OF FIELD EXPERIMENTS

The final object of field experiment programmes is generally an improvement in the yield or quality of crops or other agricultural products. From the point of view of governments, the eventual aim is greater food production or an increased out-turn of economic products. Agricultural organizations are likely to place more importance on increasing the farmer's profit as well as his production. With manufacturing firms the emphasis will probably be on the comparison of a new material with old and established ones from the point of view of greater effectiveness and lower cost.

For all these purposes field experiments provide the final basis for judgment, and nothing else can take their place. Pot culture and laboratory work are valuable in preliminary studies and in various ancillary ways. But a host of factors operate in the field which cannot be exactly reproduced in the laboratory or glasshouse, and any or all of them may critically influence the performance of a

chemical, cultivation treatment, or crop variety. Laboratory tests of soil samples, unless closely related to field experiment results, give indications that can be badly—and expensively—misleading [2, 6]. All these methods provide only indirect answers to the really important question: what is the effect of a treatment in practice? For the man who has to make decisions, no other approach can give such confidence as a sufficient array of field experiment results.

Acceptance of these principles is by no means general, or if lip service is paid to them they are not put into effect. It will therefore be the special purpose of this article to draw attention to the importance of adequate field experiment programmes in matters concerned with agriculture, and to illustrate what is needed and what can be done by examples of the kind of thing that has already been achieved. As to the technique of experimentation, it must suffice to state that the designs used must be statistically sound, with randomization, even though individual trials may be unreplicated. Full use must also be made of modern statistical methods in planning programmes, in the layout of experiments, and in the interpretation of results [11, 25]. The statistical appraisal of the amount of expenditure that is justifiable has been discussed by Yates [24].

Main attention will be given to fertilizer experiments, because this is the field with which the writer is most familiar and it has been developed very extensively. Similar considerations apply, however, to evaluation of the effects of other treatments of agricultural importance such as crop breeding, pest control, and methods of cultivation. Sometimes, as with irrigation, the advantages may be so obvious that they need no demonstration; but whenever it is desired to measure a benefit or to estimate its value, field experiments are required.

In fertilizer studies the first subject of enquiry is usually into deficiencies and requirements of the major plant nutrients, nitrogen, phosphate and potash. Where minor elements seem likely to be deficient, all should be tested for, preferably in

multi-factorial experiments in which both soil and foliar applications are compared. This aspect has been well reviewed by Greene [14]. With the major elements it is sometimes possible to simplify the work by testing for only two of the nutrients; but it should not be too lightly assumed that any one is unimportant. It is the nutrient deficiencies that govern fertilizer responses, and it is the responses to fertilizers that provide the increases in production which are the final "object of the exercise." A farmer's aim in using fertilizers is to increase his profits as well as crop yields, and with this in view he should neither apply uneconomic rates of a plant nutrient that is needed, nor use more than maintenance quantities of nutrients with which the soil is already well supplied. National economy also requires that fertilizers should not be wasted.

Countries that have carried out adequate programmes of fertilizer experiments are much better able to use fertilizers efficiently than those that have not. The value, even in their early stages, of field experiments planned on a national scale has been shown by Yates [25]. Referring to India, he stated that for a given crop the farmers were putting the same amount and type of fertilizer over the whole of a State or the whole of the country, regardless of soil types and other factors known to affect requirements. The field experiments showed that, with adequate water supply, nitrogen gave a fairly constant response over most of India; it was reasonably safe, therefore, to recommend a general small dressing, confident that all farmers would get a profitable return and that the fertilizer would not be misused. But with phosphate just the contrary held. For a long time it was said that phosphate was not worth putting on in India, yet trials on cultivators' fields had revealed regions where phosphate was required and profitable. This was not true of all regions, and if phosphate was recommended for universal adoption a large amount would be wasted. More experimental work was needed in India with potash, which had formerly been neglected but was now found in some districts to give as good a response as phosphate.

Dealing with quantitative aspects, Yates concluded that the whole production of Sindri (a synthetic nitrogen plant having an output of about 350,000 tons of fertilizer a year) if properly used on paddy would give somewhat over half a million extra tons of rice a year—enough to provide food for $2\frac{3}{4}$ million people. His estimate of the develop-

ment work needed to take care of an increase in population of the order of 200 million people included 15 fertilizer plants of the size of Sindri. The article as a whole illustrates the important general conclusions that are possible from adequate field experimental programmes.

THE REQUIREMENTS OF EXPERIMENTAL PROGRAMMES

It is not always realized how large is the number of experiments or trials that must be carried out in order to get sound information. Crops differ in their requirements, and results are strongly influenced by soil and climate. Thus if the conclusions reached are to be a reliable guide to practice the experiments must be numerous enough to provide a fair sample of the main soil and climatic conditions in the territory under study, and they must be continued for a number of years. Plant breeders have long been reconciled to testing their new varieties in a wide range of localities, where soils and climates differ; with problems of pesticides or of cultural methods, on the other hand, results from a limited number of localities comprising the main variations in natural conditions may suffice. It is with experiments on the nutrient status of soils or on fertilizer effects that the problem of a sufficient number of experiments is most pressing.

Fertilizer field experiments are costly, time-consuming, and laborious, and there is a natural tendency to cut down their numbers or even to avoid doing them at all. Work on a national scale may necessitate scores or even hundreds of experiments on each main crop; yet the value, for a whole territory, of the increased production or greater economy resulting from an adequate series of experiments is great enough to make the cost well worth while. For example, a crop covering a million acres may yield a product worth £20 million, and an effective programme might show how to raise the average output by 10%. This would mean an increase in value of output of £2 million every year, continuing indefinitely. The cost of say £10,000 a year for a programme of 50 experiments annually, lasting five years, would seem a small price to pay for initiating so great a benefit. By contrast, a programme consisting of a few field trials at one or two localities will give misleading results when applied to a whole region, and can cause losses in crop production or wasteful use of fertilizers amounting to many times the money economized.

Where soil and fertilizer problems are concerned, the need for numerous experiments can be illustrated in terms of the sampling problem involved. A single small-plot experiment on a crop covering a million acres is a sample of the order of one-millionth part of the area on which the crop is grown; even a hundred experiments would represent only about a ten-thousandth of the area. It is not strange that investigations based on only a few experiments should give misleading results.

Distinction should be made between fundamental investigations of long-term value and more *ad hoc* studies, often planned on a short-term basis. The former class would include investigations of factors limiting soil fertility, especially nutrient deficiencies, which give information about fertilizer requirements and effects; also the influence of crop rotations on soil fertility. Typical of *ad hoc* investigations is the comparison of new fertilizers with standard ones.

Rotation experiments are the most complex to design or interpret, so it is not practicable to carry out many of them. Fortunately the answers obtained can usually be applied to wide areas of similar soils and climates. Comparisons of different kinds of fertilizer, to be of practical value, need fully replicated and accurate designs but only a limited number of representative sites. The experiments requiring most repetition and widest distribution are those on soil fertility or fertilizer requirements, because these can vary literally from field to field; enough must be done to cover the main types of soil and climate, and if soundly based advice is to be given to individual farmers the experiments must be supplemented at least by simple field trials in order to allow for local variations. Where the effects of treatment under ordinary farming conditions are required, most of the experiments should be done on private farms and not at experimental stations.

EXAMPLES OF COMPLEX PROGRAMMES

England

An outstanding—perhaps the first—example of a satisfactory field programme was the sugar beet manuring investigation carried out in England from 1933 onwards by Rothamsted Experimental Station in co-operation with the beet sugar factories. About 20 experiments were laid out on a different site every year, so that by 1949 the total number of “centres” was over 300. This represented almost one experiment for 1000 acres of

beet, which the results proved to be a satisfactory degree of sampling.

The main findings only have been published [1, 7, 9, 12]. When the investigation began, the manuring of sugar beet was in a very unsatisfactory state, being based largely on tradition or unsupported guesses. Fertilizers were sometimes applied wastefully or in inadequate amounts, and the national average yield was relatively low. The experiments showed clearly which plant nutrients were required by this crop on the different kinds of soil and which fertilizers were therefore most effective in raising yields; information was obtained also about the best rates and ratios of application of the individual nutrients. Special problems like the use of salt as a fertilizer and the need for boron were also examined. As a result the manuring of sugar beet is more firmly established on a scientific basis than that of any other crop in England; even wheat and potatoes are less well understood and less efficiently manured.

Soil samples were tested for available nutrients, and laboratory results were compared with those from the field. It was found, despite discrepancies with individual soils, that fertilizer responses were higher on the average in the soils shown by analysis to be deficient in the corresponding plant food [7]. It was also shown, over the whole series of experiments, that if phosphate and potash fertilizers had been applied to sugar beet on the basis of soil test findings, considerably greater yields and profits would have been obtained than if the same quantities had been applied indiscriminately [8]. This demonstrates the value of laboratory soil tests when the methods have been selected and standardized on a basis of the field experiment results. Without this standardization the relationship between chemical tests and practical results cannot be relied on.

All field experiments in this investigation were factorial designs, beginning with $2 \times 2 \times 2$ NPK experiments (presence and absence of N, P and K) and soon going on to $3 \times 3 \times 3$ NPK designs (each nutrient at 3 levels, laid out in unreplicated designs with confounding of higher order interactions). These proved satisfactory for many years, although more complex designs with additional factors were introduced later. All experiments were laid out under skilled supervision on ordinary farms distributed throughout the sugar beet growing districts.

The whole investigation was a model of planning and execution, and it could still be taken as a

model by any authority that wished to obtain reliable information about the fertilizer needs of important crops on a country-wide scale. The chief modification that might be made would be to carry out more experiments each year, so that a reasonable degree of completeness would be obtained in fewer years. For less valuable crops than sugar beet, or crops covering much greater areas, the density of experiments of one to 1000 acres of crop might be considered too great, involving an expenditure out of proportion to the degree of accuracy needed. Indeed, for many countries such a programme would certainly be too expensive; and it is necessary to find less costly means of obtaining information even at the sacrifice of reliability in detail.

It is possible to obtain information of practical value from a much smaller sampling ratio if the experiments are well carried out and widely distributed. The general value and the applicability of information about manuring are greatly increased if the results can be related to the kinds of soil: this is usually possible for the major genetic soil groups, if not for the surveyor's soil types and series.

China

An example of such an investigation which covered an area equal to a sub-continent, namely agricultural China, and which included many crops, has been described by the author [19]. The purpose of the paper was to demonstrate the value of fertilizer field experiments as "soil tests," i.e. tests of the available nutrient status of soils. The phrase "soil test," frequently applied only to chemical or biological tests on small samples of soil, can equally well be used for field experiments in which the chemical fertilizers might be said to take the place of reagents in the laboratory. The results not only indicate the extent of nutrient deficiencies in the soils, but as they are given in the form of yield responses they provide a direct measure of the increases in crop production that can be obtained by using fertilizers.

Experiments in this series, primarily of factorial NPK designs, were carried out throughout central and western China during the war years. In the main programme the standard rates of application were 0, 27 and 54 lb./acre of N, P_2O_5 and K_2O . The chief crops were wheat, paddy rice, cotton, rapeseed, maize and millets; there were experiments also on barley, sugar-cane, Irish and sweet potatoes, and other crops.

Before the war considerable numbers of fertilizer trials had already been done in east China. Although few of these were of the "NPK test" type, many fulfilled the essential conditions of "soil tests": they were single-year experiments or the first year of continuous experiments; they employed soluble chemical fertilizers, and organic manures were not used; if only one element was being tested, the others were present as a basal dressing. By combining all suitable experiments, practically the whole of agricultural China was included in the study.

Results were brought together by the method of Crowther and Yates [10]. Constants and conversion factors were calculated for individual crops from the results of Chinese field experiments at more than two levels, and these were used to convert the fertilizer responses, obtained at various rates of application, to responses at the standard rate of 54 lb./acre of nutrient.

This work was part of a still larger undertaking, namely the conversion of the results of all Chinese fertilizer field experiments, whatever their type, to responses at standard rates. For the present study, results of suitable experiments were grouped into a "soil test" series. Over 600 experiments of all types were involved, with over 300 of the "soil test" type on the six principal crops.

Certain general trends were manifest. With all crops the average response to N was larger than that to P, and with all crops but maize (where the difference was negligible) the average response to P was larger than that to K. It follows that the soils tend to have a status low in available N, moderate in P, and high in K. This holds good for almost all crops over most of the great soil groups of China.

This result is clearly related to the traditional and long-continued use of local manures, such as dung, compost, night soil, oilseed cakes, plant ashes and pond mud. Practically all these materials are much richer in potash than in phosphate, in consequence of which the status of the soils in available potash has been maintained at a higher level than in phosphate. Nitrogen, however, is readily lost by leaching, and such natural sources of "recuperation" as free-living nitrogen-fixing organisms (including blue-green algae in paddy fields) and leguminous green manures have not sufficed to do more than maintain a relatively low status of available nitrogen in the soil.

Differences between crops in their responses to fertilizers would repay further study, but these are

complicated by regional differences in the distribution of crops; most of the maize, millet and cotton experiments were in central and north China; most of the rice and rapeseed in central and south China; wheat was the most widely distributed crop. Rapeseed, which has a distribution similar to that of rice, was found to be more sensitive than rice or other cereals to phosphate deficiency, and in this it resembles other cruciferous crops in western Europe. Results for rice have been discussed in detail elsewhere [13, 20].

There were clear-cut differences between different soil groups and classes in their nutrient status and fertilizer responses. J. Thorp [23] has described the genetic soil groups in China, and has pointed out that these fall into the two main classes of pedocals and pedalfers, which he calls more simply calcium and leached soils [4]. Calcium soils occur chiefly in the wheat region of north China, which has a relatively dry climate; leached soils occur chiefly in the rice region of the centre and south, where rainfall is higher.

When results from the "soil test" experiments were classified according to the kind of soil on which they were done, there were consistent differences between the two main soil classes. With every crop where a comparison was possible, leached soils gave a larger response to P and K than did calcium soils, clearly demonstrating their lower status in these elements. It has been found elsewhere that soils with a high calcium content sometimes tend to show potash deficiency, but in China the calcium soils are so well supplied with available potash that the use of potassic fertilizers tends, if anything, to depress crop yields.

Responses to N showed less marked soil effects than those to P and K. With summer crops (rice, maize, millet and cotton) mean yields and nitrogen responses of the two soil classes were lowest on the leached soils, presumably owing in part to poorer fertility occasioned by leaching of nutrients. With winter crops (wheat and rapeseed), however, both yields and nitrogen responses were highest on the leached soils, probably because lack of moisture limited growth on the calcium soils.

The nutrient status of the genetic "great soil groups" in China was also examined, and the results of these and the other field experiments were used as a basis for generalized fertilizer recommendations for Chinese soils and crops. The magnitudes of the average responses showed how the use of chemical fertilizers could help to solve the problem of feeding China's growing popula-

tion. For example, with the "soil test" experiments on rice the sum of the average responses to the major nutrients, at 0.5 cwt./acre of N, P_2O_5 or K_2O , was equal to nearly 40% of the yield of the control plots. By applying fertilizers to rice according to the needs of the local soils, and in addition to manures normally used, food could be grown for at least another 70 million people.

These investigations may be used to give some indication of the numbers of field experiments that are needed to provide useful general results. The total cultivated area covered about 200 million acres, and one "soil test" experiment to 700,000 acres was sufficient to demonstrate important effects or major differences in fertilizer requirements. It is rather remarkable that so small a sample should have been adequate, but this could be expected only when the total crop areas were of the order of many millions of acres.

Turning to individual crops, the best results (i.e. those in best agreement with each other and with theory) were given by paddy rice. There were 81 "soil test" experiments on this crop—one to 900,000 acres under rice. Paddy rice is known to be less variable experimentally than many other crops, largely because with it water is not usually a limiting factor. At the other extreme, cotton had 56 and rapeseed 42 "soil test" experiments, giving one experiment to 250,000 and to 330,000 acres respectively. In spite of the larger sampling fraction with these two crops, agreement with each other and with comparable crops was rather poor where individual soil groups were concerned (some of which were represented by only a single experiment), although for the two major soil classes the average results fell into line with those for other crops.

In fact, the actual number of experiments contributing to an average is important, as well as the degree of sampling implied by the area of crop represented by one experiment. Where crops or soil groups were represented by fewer than 20 experiments, the general agreement with other crops or with theoretical expectations was surprisingly good, considering the sampling problem involved; yet there were unexplained discrepancies, and only where a crop or a soil class was represented by over 40 experiments could some confidence be felt in the numerical values of the averages as well as in their general order.

It is also worthy of note that when the results of the other 300-odd field experiments were compared with those from the "soil test" series general

agreement was good, allowance being made for the effects of local manures.

Kenya

A large-scale investigation based wholly on complex experiments has also been undertaken in Kenya [15]. In the Highland Fertilizer Scheme, formed by the co-operation of the Kenya Government and I.C.I. Ltd., 251 complex factorial experiments were laid down on commercial farms, and 172 of these were harvested, over a period of 3 years. The investigation was limited to the Kenya Highlands, wheat and maize being the main experimental crops. The combined area of these two crops varied around 350,000 acres, so that there was harvested one experiment to about 2000 acres. Soil samples from the experimental plots received a comprehensive chemical and mechanical analysis. Responses of the crops to N, P and K were determined and related to soil groups and properties; different kinds and rates of phosphatic fertilizer were compared. It was found that phosphate was the chief deficiency suffered by cereals on these soils, and that the use of suitable phosphatic fertilizers would greatly increase cereal production and add about £3 million annually to the income of the Highland farmer. At the average cost of £138 per experiment harvested, totalling £25,000 for the 3 years, the potential return on this investment is great.

Damage by wild animals and other mishaps were responsible for the failure of nearly 32% of the experiments laid down. This illustrates that, even if the proportion of "casualties" is high, valuable results can still be obtained provided enough experiments have been done.

Another point of importance was the smallness of the staff required to handle the field work: there were only two field bases, each with a European assistant, an African headman and 12 African labourers. Each centre covered farms within a radius of about 50 miles. Further headquarters staff were required for planning and statistical analysis; but since a shortage of field staff is sometimes regarded as an obstacle to large experimental programmes it is worthy of comment that something like 50 experiments on ordinary farms per year could be handled by one trained man with untrained assistance.

EXAMPLES OF SIMPLE PROGRAMMES

Where resources permit, programmes based on large numbers of complex experiments, such as

those referred to above, are certainly to be preferred. But in some countries it may not be possible to procure funds or men on the necessary scale. For such areas cheaper programmes having a limited number of complex experiments, supplemented by numerous and widely distributed simple trials on ordinary farms, can give results of sufficient reliability for many purposes. Schemes restricted almost entirely to simple trials are unsatisfactory. A certain number of large factorial experiments at several nutrient levels are needed to provide a control and standard of reference for the simple trials, to furnish response curves that can be used to determine the optimum rates of application, particularly with reference to costs and profits, and to give information about interactions and the best nutrient ratios. Experimental programmes of this kind have been discussed in recent years, notably by Stewart and Crowther [22].

Gold Coast

An excellent example of a programme planned along these lines is the investigation of soil fertility and of fertilizer needs in the Gold Coast, reported by P. H. Nye [16].

First, in 1948-9, came 84 multi-factorial experiments at agricultural stations, widely distributed throughout the country, which gave a good general picture of the fertility and nutrient requirements of the soils. These were followed by about 600 simple unreplicated trials on African farms, 70% of which were successfully harvested. Considering the many problems involved in carrying out trials on the land of peasant farmers, this was a notable achievement. The trials were numerous enough to give the information required, despite casualties. For the total crop area of 1,600,000 acres there was one replicated experiment to 19,000 acres and one simple trial to 3600 acres.

A small staff was able to carry out the work: in each area the trials on peasant farms were organized by a district assistant, who handled from 15 to 20 sites, aided by a specialist assistant who could manage two small areas or one large one. The field work was done by native labour.

The scheme included the chief local crops, and the experiments were laid out in careful relation to the main soil groups. Analyses of soil samples from all sites were compared with the fertilizer responses.

The field results showed, briefly, that forest (high-rainfall) soils did not give appreciable responses to nitrogen, whereas some savannah (low-rainfall)

soils gave large responses, depending on the crop and the previous history of the field. On the other hand, responses to superphosphate were large on forest soils, and those on savannah soils varied with the present and the previous cropping, as well as with the geological parent material of the soil. Some large positive interactions occurred between N and P (showing the value of using factorial designs), and these would be important in practice. Potash was generally ineffective.

Among other problems studied were the effects of local manures, residual effects of fertilizers, and the responses to different rates and times of application of N and P. The combined results made it possible both to give sound manurial advice to the farmers in each district, and to draw general conclusions concerning the best use of fertilizers, from the point of view of profits as well as production. It was shown, for example, that the productivity of one impoverished northern region could be increased 75–100% by very moderate use of fertilizers and more attention to organic manuring.

India

In India investigations along similar lines, covering much larger areas but initially on a less closely organized plan, have been and still are going on. Before the last war, numerous replicated fertilizer experiments were done by State agriculturists on experimental farms and by commercial firms. They were not always well planned for the purpose now in view, and they were widely divergent in type, but they gave much useful information which has been brought together and reviewed [5, 21]. Those done on experimental farms suffered from the fact that the farm soils were generally more fertile than the surrounding countryside. More recently, individual States as well as the Indian Council of Agricultural Research have been undertaking extremely large programmes of simple trials on cultivators' fields.

Results both from earlier experiments and from simple trials, including some thousands in Bihar up to 1952–3, have been summarized and discussed by Yates, Finney and Panse [26]. They show that food grains would respond well and highly profitably to nitrogen, less generally and less profitably to superphosphate, and usefully in some areas to potash. The authors point out that if half of the rice area were given nitrogen at 20 lb./acre it would require 1.6 million tons of sulphate of ammonia and would yield 3.0 million additional tons of husked rice: this would represent a 15%

increase in the present yield of rice for the whole country.

Further simple field trials, on the scale of many thousands annually, are not only providing important information but are proving to be very effective demonstrations of the value of using fertilizers, and there is no doubt that they will play a major part in increasing food production. Results of over 4000 trials have recently been reported [3] and the findings from recent complex experiments have been reviewed [17].

If simple trials are correctly designed and laid out, their results are statistically valid, no less than those of more complex experiments. In east China before the war, simple fertilizer trials were laid out in such a way that there were several—perhaps 5 or 6—distributed around a single village, each trial representing one block of a randomized block design. Results of the village group of trials were analysed like a single randomized block experiment having 5 or 6 replicates, and the coefficient of variation was frequently found to be little or no higher than that of fully replicated experiments in the same territory. Even where the C.V. was high, significant and useful responses could still be obtained, and although the information about individual fields was not dependable, recommendations applying to all the lands of the village could be made. The statistical aspects of such trials are ably discussed by Panse and Sukhatme [18].

CONCLUSION

It is a curious and striking fact that, except for sugar beet in England, all the major investigations described above have been carried out in countries sometimes regarded as technically backward. There are large and technically advanced countries, both in the Commonwealth and outside it, which have made no such systematic attack on the problems of soil fertility and of the best fertilizer rates and ratios to employ, although they use large quantities of fertilizers. This is probably because a tradition of fertilizer usage has grown up, based on experience, which leads the local agriculturists and manufacturers to think that the answers are already known. Even if this were true twenty years ago, it is not likely to be true today.

The available nutrient status and the fertilizer needs of soils are not static; in addition, new or cheaper fertilizers and new crop varieties are constantly being produced which require a fresh approach to fertilizer usage. It would be well if some of the more highly developed countries

would overcome their complacency in the matter of fertilizer information and carry out investigations along the lines of those done in the less advanced territories. There would be some surprises and upsets of accepted beliefs; at the same time larger increases in production and a much more efficient use of fertilizers would ensue.

A matter of fundamental importance is that the nutrient status of soils is constantly changing, especially under modern agricultural systems. For instance, a group of soils may originally be found to be deficient in, and to respond to, phosphate; after years of manuring with phosphates the residues build up in the soil and the deficiency is overcome; eventually a major deficiency may develop in nitrogen, or potash, or both, because the heavier yields obtained with phosphate have removed more of the reserves of other nutrients from the soil. Thus a region where phosphates are traditionally used may today be in more need of nitrogen and potash. Similar circumstances may hold good for a minor element like magnesium, a deficiency of which sometimes develops where heavy potash manuring has been used. The nutrient status of the soil, therefore, requires constant watching. A major investigation of the type described will define the deficiencies and responses of a territory as it is today; but these will certainly

be different in a quarter-century's time. Consequently there is a need for a continuing programme, or repeat work on a smaller scale at intervals of a decade or so, in order to keep track of changes as they occur. Unless this is done there is always the danger that the full effects of fertilizers are not being obtained, and that materials are being used inefficiently or wastefully.

The purpose of this article has been to illustrate, from examples of what has actually been done, the fact that large field experiment programmes are not unduly difficult to carry out, even with limited resources, and that they give results of the greatest possible value. These results concern not only the factors limiting soil fertility but also the large increases in production that can be obtained with fertilizers. The national and economic value of such increases, continuing as they do year after year, is so great that the cost of even an extensive field experiment programme is small by comparison. The programmes may none the less be too costly to be undertaken in full by private organizations, but their benefits are so widespread that they should be a matter of government action; it is sometimes possible for both private and government organizations to co-operate in planning and carrying out such programmes, and this is likely to prove to the advantage of both parties.

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WILD OATS

J. Stubbs

Few weeds of arable land are so difficult to eradicate as wild oats, mainly owing to the persistence of seeds in the soil and kinship of the species to cultivated cereals. Cultural measures are beneficial but limited in application. Chemical treatments have proved of value in broad-leaved crops, and there is hope that they may yet reduce the weed in cereals, though much work must be done before this can be achieved in practice.

One of the most troublesome weeds of arable crops in temperate regions is the wild oat. When agricultural conditions favour its development it rapidly becomes established in cereal crops, sugar beet, peas and flax, increasing the costs of cultivation and reducing yields and quality of the crops. Two main species are involved: *Avena fatua*, which is the more widespread, and *A. ludoviciana*, which is largely confined to S. and Central Europe. Both are admirably adapted as cereal weeds, for their seeds can remain dormant for long periods, their germination season overlaps that of the cereals, and they mature and shed many of their seeds before harvest. Fallen seeds, aided by twisting of their awns, quickly get buried in cracks and under stones and clods, where they are retained by their long hairs. Later ripening seeds remain as impurities in the crop seed. These factors and close kinship to the cultivated cereals make the weed very difficult to control.

BIOLOGICAL FEATURES

Distribution and Spread

There are many references to the distribution and importance of wild oats as weeds of arable land. Only recently, however, have detailed surveys been made of their incidence in cereal-growing areas. In England a joint N.A.A.S.-Rothamsted survey made in 1951 showed that *A. fatua* was present in all areas growing spring or winter wheat and barley and on all soil types, whereas *A. ludoviciana* was restricted to an area with a radius of 80 miles centred on Oxford, and occurred mainly on heavy soils and in winter wheat [45]. In the following year a "roadside" survey covering nearly 500 fields in East Anglia revealed that, excluding oat crops, 29% of all winter cereals and 12% of spring cereals carried an intense infestation of wild oats [13]. Wood [49] reports that, in the Great Plains Region of N. America, of a total of 106 million acres under cultivation 61 million acres carry wild oat infestation, 29 million being classed as severe.

It is now well known that wild oats are introduced and spread mainly by infested seed. Direct

evidence has shown that *A. ludoviciana* came to Britain from France in seed wheat imported during the 1914-18 war [45], and similar introductions of wild oat species in seed or feed have been made to other lands. Although no seed surveys have been carried out in the U.K., the importance of infested seed is recognized. In East Anglia in 1942-52 nearly 46% of refusals of certificates in the Field Approval Scheme for Cereal Seeds were attributed to the presence of wild oats in the crops [13], and of 63,873 acres inspected in England under the Cereal Inspection Scheme 28.1% were considered unsuitable for seed production for the same reason [24]. In consequence, a committee working on the revision of the Seed Act has recommended that *A. fatua* be added to the list of injurious weed seeds and that cereal seed samples be increased from 4 oz. to 6 oz. to enable a more accurate check on the incidence of the weed. Furrer [17] reports that in Minnesota, N. and S. Dakota, Saskatchewan and Alberta upwards of 54% of seed samples contained wild oats. In a drill box survey in N. Dakota [33] an average of 7 wild oat seeds was found in each pound of grain, which represents a seeding of 504 per acre. Since each wild oat plant produces on an average 250 seeds, and many of these are shed before harvest, the use of infested seed quickly leads to major infestation.

Competition between Crop and Weed

Pavlychenko [36] discusses this subject at some length. On the basis of the amount of dry matter produced he found that growth of the weed was least in barley, with spring rye, flax, oats and wheat in descending order of competitive efficiency. The greater competitive effect of spring barley over spring wheat was demonstrated in pot tests by Thurston [44], who also showed that early sowing and establishment of spring cereals had a useful effect in minimizing the multiplication of wild oats. The importance of this in the field was clearly demonstrated at Rothamsted [43], where autumn-sown cereals caused a greater reduction of *A. fatua* than did spring cereals. This effect appeared to

depend on the size of the crop plants at the time the wild oats were germinating rather than on specific inhibiting effects, such as have been attributed to rye in Sweden. On the other hand, Pavlychenko [36] has shown that, under arid conditions, the type of root system may well affect the degree of competition. Thus barley, which has more seminal roots than other cereals and a greater horizontal root spread, is potentially a more effective competitor than wheat or rye when soil moisture is low.

Many generalized statements on crop losses due to wild oats are available, but few detailed studies have been published. In Canada the percentage reduction in grain yield caused by infestation of wild oats in barley, spring rye, wheat, oats and flax has been given as 15.3, 28.8, 28.1, 45.7 and 85.1 respectively [36]. Striking figures representing the effect of wild oats on the yield of spring wheat were obtained in a trial in England [2]. By delaying the sowing of spring wheat for just over three weeks the number of wild oat plants to the square yard was reduced from 40 to 3 and the yield of wheat grain rose from 12.3–23.3 cwt./acre.

Dormancy, Germination and Longevity

Dormancy, when associated with reasonable longevity of the seed, is an important factor in the survival of annual weeds of arable crops. Wild oats are admirably adapted in both respects, and an excellent review of this subject has been given by Thurston [41]. As long ago as 1914 Atwood [5] found that dormancy of wild oats was due to the impermeability of the seed coat to oxygen. This finding has been confirmed by later workers, pricked seeds germinating in the laboratory within twenty-four hours. Dormancy varies, however, with locality and season. It is affected by the manganese status of the soil [40]. It also tends to become greater later in the season, which leads Lindsay [29] to suggest that a chemical inhibitor may be involved.

The effect of environmental conditions on the germination of *A. fatua* has been investigated by Brown [9]. Seed kept in uninterrupted dry storage at 70° F showed relatively little dormancy, whereas the germination of seed kept outdoors in damp frozen soil was greatly reduced. Other work [45] has demonstrated that the dormancy of imbibed seeds of *A. fatua* was greatly increased by exposure to high temperature (27° C), whether constant or alternating with cool conditions (5–10° C). In contrast, *A. ludoviciana* showed no residual dor-

mancy after such treatments, inhibition of germination at 27° C being overcome by cooling.

Dormancy of *A. fatua* was found in Canada [25] to be affected by the position of the seeds in the spikelet and of the spikelet in the panicle, but work in England [44] has shown that cutting off part of the panicle had no effect on the dormancy of the remaining seeds of *A. fatua*, although it did increase the percentage germination of the first seeds of *A. ludoviciana*. In field and laboratory the primary grain of the latter species normally has less dormancy than other seeds in the spikelet [41].

Bibbey [7], working with *A. fatua*, suggests that primary dormancy disappears during the first winter and early spring after-ripening period and that the seeds are then readily germinable. Subsequent dormancy is related to environmental factors. Similar conclusions were reached by Thurston [41, 42], who suggests that decomposition of the seed coat by soil micro-organisms is responsible for breaking primary dormancy of the two species. Additional factors must affect *A. ludoviciana*, for germination of the pricked seeds is very inconsistent, probably owing to secondary dormancy.

That both species germinate more readily on cultivated than on uncultivated soil has frequently been observed. Bibbey [6], for example, reports that under Canadian conditions germination increased sevenfold on tilling the soil.

Agreement is general that depth of placement affects germination. Brenchley and Thurston [8] state that germination occurs most readily in the top 3 in. of soil and less readily at 5–6 in., but even at 9 in. some germination takes place. Thurston [41] found that *A. ludoviciana* gave more and sturdier seedlings than *A. fatua* from seeds sown at 6–9 in., although seedlings from the deeper sowings were weak and yellow on emergence. At depths down to 20 in. the seeds remain dormant, but germinate on being resown less deeply. Deep ploughing may therefore increase infestation by bringing dormant seeds to the surface.

With *A. fatua* germination can take place throughout the year in English conditions [13], although peaks occur in autumn and spring. Germination of *A. ludoviciana*, on the other hand, is largely restricted to autumn and winter because it reaches its optimum at a temperature around 40° F and is inhibited at 60° F [42].

Longevity of wild oats under natural conditions has been the subject of much speculation. Claims of long persistence under grass, based on appearance of the weed after ploughing up, are suspect,



FIG. 1. Infestation of wild oats in wheat. (By permission of Rothamsted Experimental Station.)

FIG. 2. Wild oat seeds. Top: *Avena fatua*. Bottom: *A. ludoviciana*. Left to right (both rows): Whole spikelet, first "seed," second "seed," third "seed," showing abscission scar at base of all seeds of *A. fatua* but only on the first "seed" of *A. ludoviciana*. Note also that there is no awn on the third "seed" of *A. ludoviciana*. (By permission of Rothamsted Experimental Station.)



because the infestation may have arisen from seed introduced with that of the arable crop. Seed of *A. fatua* is known to remain viable for at least four years, and that of *A. ludoviciana* has a somewhat shorter life in the soil [12, 41, 43]. The survival of wild oats under a grazed ley is at present being investigated at Rothamsted [44].

CONTROL MEASURES

Cultural Methods

The features described and other considerations make it difficult to control wild oats by cultural measures, and economic factors tend to limit the practicability of altering farming systems, yet efforts to reduce infestations by these means continue to be made.

Many attempts have been made to eradicate the pest by providing conditions that most favour germination of the seed and then destroying the seedlings before sowing the cereal crop [9, 12, 27]. Such treatment should be followed by sowing a highly competitive cereal, early-maturing barley probably being the best [36, 44]. Some success has also been obtained with late-sown wheat [1].

Another method, tested by Thurston [42–44], is to smother the weed with heavy stands of autumn cereals. Used for this purpose, wheat and rye reduced infestations of *A. fatua* to negligible proportions in the year of trial, and winter and spring barley gave 75% and 25% control respectively. Unfortunately reductions obtained in this way apply mainly to one season and there is no long-term effect, for the remaining plants seed prolifically and the reservoir of seeds in the soil is not materially depleted. The method, too, is restricted to *A. fatua* in regions where winter cereals can be grown: the winter-germinating *A. ludoviciana* flourishes under the system and can be so controlled only in spring-sown cereals.

More promising is the use of cleaning crops in carefully planned rotations. A suitable crop is one that provides the opportunity for all wild oat seedlings to be destroyed in the season, and with careful management an adequate number of cleaning crops in the rotation can greatly reduce an infestation. The value of the method is well illustrated in the 1951 N.A.A.S.-Rothamsted survey, which dealt only with infested land. It showed that when three cleaning crops were provided over a period of four years 40% of the fields contained less than 100 wild oat ears to the acre and no field had more than 50,000, whereas with no cleaning crops the corresponding figures were 2% and 35%.

A novel method which enables flax to be used as a cleaning crop is described by Page [34]; he showed that when sheep were folded on infested flax they grazed the wild oats selectively and most of the weeds failed to set seed.

Several workers emphasize the value of summer fallows. This method is undoubtedly of use where it is not practicable to include cleaning crops in the rotation, but it is expensive and does little more than a late spring cereal crop in reducing the numbers of dormant seeds. Thus, at the end of a period of summer fallow on heavily infested land in Manitoba there remained no less than 20 bushels of viable wild oat seed per acre in the top 4 in. of soil [9]. A promising modification is to precede the summer fallow with an early oat crop which is harvested green [14].

It is evident from the dormancy and longevity of wild oats that a purely arable rotation containing cereals cannot eradicate this weed. Only ley farming shows real promise. Trials in Manitoba have proved that the weed can be effectively controlled by extending a four-year rotation of fallow, wheat, wheat, oats to six years by including a ley [9].

On clean land it is of prime importance to ensure that seed corn is completely free from wild oat seeds and that any initial infestation is dealt with by hand pulling.

Chemical Treatment

Following the discovery that isopropylphenyl carbamate (IPC) is a selective herbicide for grasses [39] much research has been devoted to the chemical control of wild oats; but owing to the inherent difficulties of selectively controlling a grass in a cereal crop most of the work has been concerned with the weed in broad-leaved crops.

Typical of this approach are the investigations into the control of wild oats in sugar beet [3, 4, 22, 31, 32, 35]. Chemicals that have shown some promise are IPC, isopropyl-N-(3-chlorophenyl) carbamate (CIPC), sodium 2,2-dichloropropionate (dalapon), sodium trichloroacetate (TCA) and disodium 3:6-endo-hexahydrophthalate (Endothal). These chemicals have been applied pre-sowing, pre-emergence and post-emergence. The most consistent results have been obtained, except in the case of dalapon, by the pre-sowing treatment, provided that the chemical had been mixed with the soil after application. With IPC this could be done most effectively by discing [35]. All the chemicals mentioned tend to retard emergence and slow down early growth of the beet [31], though it has

been found that damage caused by IPC could be reduced by delaying drilling for about a fortnight after treatment [35]. In Canada, where cultivation in spring causes excessive drying out of the soil, autumn application of the chemicals have given satisfactory results, but TCA reduced beet emergence [4]. CIPC depresses the yield; IPC retards emergence but ultimately increases the crop [31].

Against wild oats in peas, pre-emergence applications of TCA have given effective control at 10 lb./acre at the expense of some damage to the crop, but early post-emergence sprays of maleic hydrazide (MH) had little effect on either peas or wild oats [10]. Gregory *et al.* [18] tested IPC, CIPC, TCA, 3-(p-chlorophenyl)-1:1-dimethylurea (CMU), MH, dinoseb and pentachlorophenol (PCP) applied pre-sowing, pre-emergence and post-emergence. Only TCA applied pre-sowing gave effective control of wild oats, but it had a marked effect on the pea foliage, removing the bloom and giving a yellow-green oil-soaked appearance, and the yield of peas was depressed. The poor results obtained with both IPC and CIPC in these trials are somewhat surprising in view of the known activity of these compounds; this may be due in part to delays in cultivation caused by weather conditions or possibly by the method of incorporation employed, since other workers have obtained excellent control of wild oats in peas with both chemicals [15, 37, 38]. CIPC is rather more injurious to peas than IPC, and crop damage with these chemicals is affected by soil type [38].

Some attention has been given to the control of wild oats in flax [10, 15, 16, 47, 48]. TCA applied pre-emergence effectively controlled the weed but damaged the crop badly, and autumn applications have been tested in Canada with similar results. MH applied post-emergence produced a greater kill of flax than of wild oats. In general, the results of chemical treatments have been variable and the margin of crop safety has not been adequate.

Promising results have been obtained in Canada against wild oats in legume crops: applications of IPC and CIPC at various dates in relation to the planting of red clover, sweet clover and lucerne gave excellent control, with increased yields [15].

In spite of some success in these broad-leaved crops, the main problem remains that of controlling wild oats in cereals. Four main lines of attack have been investigated: the use of contact weed-

killers before emergence of the crop, treatment of autumn stubble, pre-emergence application of selective weedkillers, and treatment to render the developing grain sterile.

The use of contact weedkillers in Canada has been described by Ebell [15]. Barley was sown direct into a wild oat growth and foliage sprays of various contact weedkillers were applied immediately before emergence of the crop. This gave much the same degree of control as late tillage without delaying sowing of the crop and with the minimum disturbance to the soil. Critical timing, however, is necessary, and this may not be possible owing to weather conditions; nevertheless the method does hold out some promise, especially in arid regions where excessive spring cultivations are not desirable and the growing season is short.

Wiese and Dunham [47] speculated that autumn applications of IPC and CIPC might kill wild oats and be dissipated in spring before cereals were sown. They therefore examined the effects of IPC and CIPC, disced into the soil in autumn, on the growth of cereals and other crops sown the following spring. Under the conditions operating in these trials it was found that treatments which controlled wild oats also damaged the spring-sown cereals. A highly significant feature of this work was the discovery that CIPC at 15 lb./acre markedly reduced the population of wild oat seeds in the soil. This is of great importance, for the presence of dormant seeds in the soil has always been a limiting factor in all methods of controlling wild oats.

The recent discovery that α -chloro-N,N-diallyl-acetamide (CDAA) and α -chloro-N,N-diethyl-acetamide (CDEA) selectively control grass weeds in certain cereal crops is of special interest [19, 20, 46]. Selectivity has also been shown by 2-chloroallyl diethyldithiocarbamate (CDEC). Wangerin [46] reports that pre-emergence applications of these chemicals at 3–4 lb./acre control a variety of grass weeds, including wild oats, without damage to flax, maize or barley and with only some reduction of wheat. Apparently these chemicals are absorbed by all plants and in the resistant species are probably metabolized rapidly to innocuous compounds. As with all pre-emergence chemicals, results have been somewhat variable, CDAA being the most consistent material.

Finally, there is the possibility of inducing sterility of wild oat grains by chemical treatment. Templeman and Sexton (1945) reported that when IPC

was applied to rye at the time of ear emergence the heads were fully formed but contained no grain. Knowles (1953), however, was the first worker to investigate the possibilities of using this method to control wild oats in a cereal crop. By applying MH when barley and wheat had been in head for six days and wild oats were still in the less advanced "shot blade" stage, he obtained complete sterility of the weed seed without materially affecting the yield of either crop. Germination of barley was not affected, but that of wheat was reduced to only 9%. These observations were largely confirmed by other workers [11, 21, 28]. One difficulty has been in ensuring adequate phasic differences in development of crop and weed [11]. Even if this can be achieved, practical difficulties associated with timing and stage of application limit the use of this technique.

CONCLUSIONS

Wild oats can be troublesome weeds of arable land in certain circumstances. Such cultural measures as cultivating to destroy the seedlings, fallowing, the use of cleaning crops and late sowing of a spring cereal can reduce infestations, though practical and economic considerations restrict their use. Chemical treatments offer better prospects. Promising results have been obtained by the use of selective herbicides in broad-leaved crops, but the difficulty here is frequently that of fitting such crops into the rotation. Fortunately there are indications from recent work that it may be possible to control the weed by chemicals under conditions of intensive cereal growing, and the problem in all its aspects is now receiving more attention from the research worker than ever before, with increasing hope of a solution.

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WORM-INFESTATION IN SHEEP

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Grazing management is of paramount importance in the control of nematode worms in sheep at pasture. Experiments show that, starting with a clean sward, it is possible by rapid folding to prevent re-infection altogether and keep infestation so low that little or no damage occurs. Worm-free lambs can also be raised in this way. But difficulties arise in practice, and both management and anthelmintic treatments will normally be required.

Nematodes inhabiting the alimentary tract of sheep constitute a problem in every great sheep-raising area of the world. The chief reasons for this are that all sheep are infected to a greater or lesser degree, that the parasites are prolific egg producers and cause damage to their hosts out of all proportion to their size, and that control is extremely difficult. In Britain a dozen or so species of stomach and intestinal worms are of importance, and most of them, if present in sufficient numbers, are capable of causing the death of a sheep. Certain anthelmintic drugs, notably phenothiazine, are effective against many of these worms, but no drug is at present effective against all of them, nor can every individual worm be eliminated. To some species, e.g. *Nematodirus* spp., there is as yet no real answer.

Nevertheless, it is frequently possible by anthelmintic dosing to prevent the disease at a clinical level or to cure it should an outbreak occur. It is partly for this reason that the effects of sub-clinical worm-infestation on the productivity of sheep have been intensively studied in recent years. These studies suggest that the loss due to normal infestations is of considerable economic significance,

though sheep at these levels exhibit no clinical symptoms and gain weight at a normal rate. The loss therefore may be unsuspected by the farmer, and it is important to assess its magnitude.

SUB-CLINICAL EFFECTS

Gibson (1954) found that Dorset Horn lambs infected with moderate numbers of *Trichostrongylus axei* gained 30 lb. per head less than comparable but worm-free controls over a period of one year. At the Grassland Research Institute a similar result was obtained with Clun Forest lambs infected with *T. axei* at even lower levels [25]: the infected animals gained 17 lb. per head less than their worm-free controls in a year—a difference in rate of live-weight gain of about 27%.

It is clearly important to know how these experimental infestations compare with those of normal sheep at pasture. One index of the worm-burden carried by a sheep is the number of nematode eggs passed in a unit of the animal's faeces. This has to be interpreted with caution and is most reliable when expressed as a mean for a number of animals and considered over a period of time. In Figure 1 the average number of eggs per gram (e.p.g.) of



FIG. 1. Average egg count (all species except *S. papillosus*) of sheep from birth to one year old.

fresh faeces is shown for a normal cross-bred flock of sheep from birth to 1 year old. The curve will vary from year to year and from flock to flock [6]; that given here, which has a peak of 1100 e.p.g., is in no way abnormal.

In the experiment with the Clun Forest lambs, however, the average egg count did not rise above 500 e.p.g. even at its peak, strongly indicating that the 27% depression of live-weight gain was associated with a level of infestation well below that characteristic

of the normal flock. These trials were carried out in indoor pens, and in order to be sure that such losses occur in the field it was necessary to repeat the same type of experiment under grazing conditions. This required a method of maintaining a control group of sheep free from worms while grazing at pasture, described later in this article. The results of one such experiment show that the rate of live-weight gain of the infected animals fell below that of the worm-free controls shortly after exposure to infection (Figure 2). Several of these experiments on the influence of worm-infestation on the live-weight gain of sheep have been described [29], and it was concluded that the depression was of the order of 15%, which is a surprisingly high figure considering that it is an estimate of the result of *sub-clinical* infestation based on differences between the production of well-managed but lightly infected animals and that of similar but worm-free sheep.

There seems little doubt that even lightly infected sheep do not grow as fast as those with no worms. This means that normal sheep do not achieve their potential rate of growth at a given nutritional level.

Since live-weight is not necessarily a true measure of the amount of meat produced, the carcasses of these experimental animals were studied to see whether differential effects occurred.

TABLE I

MEAN CARCASS MEASUREMENTS OF INFECTED AND CONTROL GROUPS OF SHEEP

Measurement	Group		Difference (%)
	Infected	Control	
Internal:			
"Eye" muscle length (A) (mm.)	67.2	70.2	4.6
"Eye" muscle depth (B) (mm.)	34.3	36.8	7.3
Shape index = $(B \times 100)/A$..	51.2	52.8	3.1
External:			
"Hooks" width (mm.) ..	191.2	200.8	5.0
Chest circumference (in.) ..	36.8	38.4	4.3
Chest depth (mm.)	309.0	318.0	2.9
Hip width (mm.)	213.0	219.0	2.8
Pelvis length (mm.)	239.7	247.0	3.0
Tibia length (mm.)	286.3	289.3	1.0
Hind cannon length (mm.) ..	230.0	232.6	1.1

So far only limited observations have been made, and these make it evident that, where differences are measurable, the infected animal produces an inferior carcass. In one experiment the infected animals dressed out at 47.8%, compared with 51.6% for the controls; in another there was a difference of 1.8% in favour of the worm-free animals. Estimates of the proportions of bone, muscle and fat indicated that the worm-free animals had a greater proportion of the more valuable parts of the carcass when slaughtered at the same age. Table I gives the measurements taken on the carcasses, as means for the infected and control groups. The external measurements have been arranged (from Hamada, 1950) in order of decreasing growth intensity at 4-10 months, the period when the infestation was at its height, hence also in a descending series from late to early developing parts. Clearly, the parts of greatest growth intensity were affected most.

It is suggested that the effect of worms is a reduction in growth rate which will produce differential effects on the carcass because of the differential development of the body parts in the growing animal [14]. Thus a heavy infestation in the early life of the lamb may reduce bone growth and cause permanent stunting. Normally a lamb acquires worms as soon as it starts grazing but does not carry a very heavy worm-burden until it is 3-4 months old, and muscle growth is likely to be primarily affected from that time onwards.

One of the most important questions in relation to the effects of worm-infestation is whether infected animals that eliminate the greater part of their worm-burden subsequently make up their loss of production. It has been demonstrated that they do not [11, 26]. They may ultimately grow as

TABLE II

MEAN APPARENT DIGESTIBILITY COEFFICIENTS ON SHEEP REARED AT PASTURE

Group	Apparent digestibility coefficient for		
	Dry matter	Crude protein	Crude fibre
Infected ..	69.7	56.9	67.4
Control ..	71.3	62.6	69.7
Difference ..	1.6	5.7	2.3

fast as worm-free sheep but they do not appear to overtake them, and although they can reach the same weight they take longer to do so. It has yet to be shown whether lambs that have suffered from worms have a higher proportion of fat when taken to the same final weight.

It is apparent that the age of the animal when it first suffers from worm-infestation will influence the effects on the carcass. Since the young animal is generally more susceptible, age will also influence the precise depression of growth rate. On these grounds, the longer an animal can be kept free from worms, or nearly so, the better. Other factors, however, must be considered.

In fat lamb production rate of growth is of primary importance. Early fat lamb is more profitable, and although the infected lamb may produce the same weight and type of carcass as the healthy animal it will inevitably be later. In this kind of enterprise the control of worm-infestation has a special significance.

Apart from the effect of worms on meat production, wool growth is much reduced [3, 18]. Experiments have shown that sub-clinically infected sheep produce 10–18% less wool than worm-free sheep. This is to be expected where the growth rate of the infected animals is depressed, for one of the factors governing the total weight of fleece produced is the total wool-bearing area, and if the surface area of an animal is reduced owing to worm-infestation it is likely to produce less wool than the potential. Assessment of any loss in wool production must also take into account the extra time an infected animal may have to be kept in order to reach a particular weight, where animals are to be slaughtered. As with meat, the same total production may be achieved at the expense of a longer grazing time and quality of the product may be inferior. When sheep are maintained over winter at a low nutritional level, the effect of worm-infestation may be considerable; in terms of live-weight gain, it may make the difference between reasonable production and none at all; in terms of wool growth, which continues when the animals

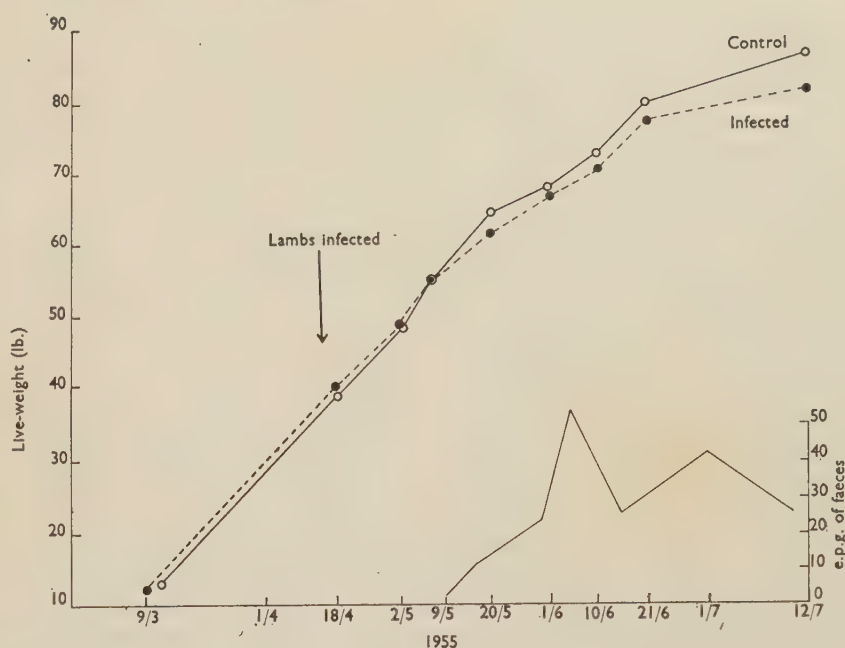


FIG. 2. Live-weight of worm-free and sub-clinically infected lambs at pasture, and (right foot) egg-count of infected group for all species except *S. papillosus*.

are merely maintaining or even losing weight, a break in the wool may occur and lead to shedding of the fleece in sheep wintered at a nutritional level just sufficient for maintenance (Figure 5).

A complete picture of the effects of worm-infestation on the productivity of sheep can be obtained only by comparing a worm-free and an infected flock. This is not yet possible, and there is little information on the influence of these parasites on the in-lamb ewe or its subsequent milk production. Yet enough is already known to suggest that productivity in sheep is seriously impaired by the presence of sub-clinical worm-burdens, even in well-managed flocks.

It has always appeared rather puzzling that these very small parasites can so markedly depress growth. *Haemonchus contortus*, with its blood-sucking habit in the abomasum, can kill a fat lamb by inducing anaemia; but most nematode species exhibit no such spectacular mechanisms by which they cause their damage. Studies have indicated that infection with *T. axei* lowers digestive efficiency in sheep [26], and this would seem to be one way in which worms damage their host, though at sub-clinical levels the effect is small. Table II shows the results of a digestibility trial using sheep infected naturally in the field and hence carrying a mixed infestation; but the controls had a rather lower worm-burden owing to their different grazing management.

In this experiment both groups consumed very similar quantities of food. Poor appetite, however, has been associated with several nematode species [1, 24, 35]. Gibson [9] found that the feed intake of sheep infected with *T. axei* was markedly less than that of worm-free sheep, and Spedding [26] has shown that very low levels of infestation can reduce dry-matter intake by 8%. Thus, at least with some species, the infected animal eats less, and such differences in feed intake can sometimes represent a large proportion of that part of the ration utilized for production.

Although reduction in appetite is not entirely responsible for the depression of growth rate [11], the fact that it does occur has an important bearing on production per acre. If infected sheep gain less weight and consume less herbage, the question arises as to how much of this loss of production can be regained by heavier stocking. The answer depends primarily on what consequences heavier stocking has on the level of parasitism, and to assess these it is necessary to understand the general pattern of infestation and the factors influencing the rate of re-infection.

PATTERN OF INFESTATION

There are two sources of infection for the young lamb: the ewe grazing with it, and the residual pasture infection resulting from any previous grazing. The consensus of opinion is that the former is generally the more important [12, 15, 16, 19]. The faecal egg-count of the ewe is normally low during the winter, but the egg output increases from April to June, and this "spring rise" is associated with time of lambing [20, 22]. Although it lasts only 2-3 weeks for an individual ewe [5], the ewe flock exhibits a curve of egg-output of the type shown in Figure 3. Infection on the pasture is also normally low at the beginning of the year, sometimes extremely so. For example, a pasture grazed by sheep until late November was found to have only one infective larva per pound of herbage in January. It should be noted that estimates of the number of infective larvae on the pasture are of necessity minimal computations.

The "spring rise" in the egg output of the ewe is



FIG. 3. Average egg-count of a ewe flock.

rapidly reflected in a rise in the number of infective larvae on the pasture, so that, by the time the lamb is grazing, large numbers are ingested with every pound of grass. Since the lamb is less resistant than the ewe, both by virtue of its age and its lack of any acquired resistance, it acts as a vehicle for rapid re-infection of the pasture. The rate at which re-infection proceeds depends on temperature, humidity, condition of the herbage, rate of stocking, the proportion of old to young animals and, above all, on grazing management. Warm, humid conditions accelerate the rate of re-infection; dry weather and extreme temperatures retard it. Long and dense herbage tends to provide a favourable environment for the development of the larvae; short pasture may cause the grazing animal to bite closer to the ground and thus consume the more heavily infected parts of the herbage. A resistant sheep returns relatively few eggs to the pasture for the number of larvae it ingests, hence a high proportion of older animals reduces the rate of re-infection. Mixed stocking operates in a similar fashion, for certain nematode species are common to cattle and sheep, and the presence of cattle—particularly older animals—tends to decrease the rate of re-infection.

As the lamb grows its resistance increases, and it is important to realize that this ability to resist infection (i.e. the establishment of ingested larvae) and its effects is greatly influenced by the nutritional status [7, 23, 34]. If the nutritional level is lowered, resistance declines, and there are critical periods, such as weaning time, when lambs may be particularly susceptible.

The pattern of infestation is further complicated by seasonal variations in the predominant worm species. An important example of this is the

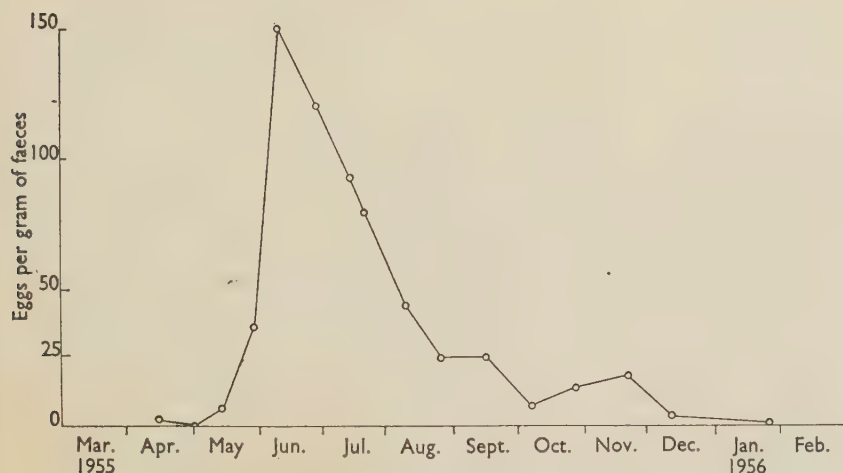


FIG. 4. Average egg-count for *Nematodirus* spp. over the first year of a sheep's life.

intestinal nematode *Nematodirus* spp. This is a characteristic parasite of lambs, and the appearance of most of its eggs in the faeces is restricted to the first eight weeks or so of summer. Figure 4 illustrates this point. Since the lamb is responsible for depositing the bulk of this infection on the pasture, one of the main factors determining whether any lamb crop will suffer from these worms is whether the pasture carried lambs in the previous year. Where the lambs graze the same pasture each year, the incidence of *Nematodirus* spp. is higher [31], and the pattern of infestation is also different, qualitatively and quantitatively, for the lamb and the ewe.

Time of year and weather will affect the rate of re-infection as much as the intensity of stocking. In fact, it is unwise to generalize about the consequences of heavy stocking. Superficially, any increase in the number of sheep per acre would appear to increase the chance of each sheep acquiring dangerous numbers of larvae, but even where the number of sheep to the acre is low it cannot be assumed that worm-infestation is negligible [21]. In hill country sheep may congregate for much of the time on relatively small areas of more palatable pasture.

A high density of stocking does not necessarily mean a high degree of infestation in the animals; more sheep can be grazed on an acre without increasing the risk of parasitism if more grass is made available for them to eat. The most important factor is the number of infective larvae per pound of herbage, and this may not be related to the number of sheep per acre. Twice as many eggs deposited on twice as much herbage may not result in an increase in the number of infective

larvae ingested by each animal. Height and density of the sward may be of considerable importance in this connection. Since most of the nematode eggs, not infective in themselves, require at least three days to reach an infective larval stage, it is evident that the length of time during which the sheep remain on the same area may influence the process of re-infection to an enormous extent. Similarly, the time which elapses between one grazing and the next will affect the number of infective larvae that remain viable. For

these reasons grazing management is of paramount importance in the control of worm-infestation.

CONTROL BY MANAGEMENT

A number of experiments have been carried out at the Grassland Research Institute to investigate management as a control, and each one has confirmed its value. It will be obvious from the foregoing that a rotational system of management, based on rapid movement to fresh pasture and a long rest before returning to any area, must retard the rate of re-infection. From 80% to 90% of the infective larvae die within about four weeks [4]; but regrowth of grass following grazing is usually faster than this, and the value of alternate grazing for sheep and older cattle lies in using this regrowth without appreciably adding to the infection present. Growing grass for hay, silage or drying ensures a longer period of exposure of infective larvae to adverse environmental conditions, and the vast majority of the larvae removed with the crop are destroyed in the process of conservation.

Rotational grazing systems, therefore, tend to reduce the rate of re-infection. But management can go further and, to all intents and purposes, prevent re-infection altogether. To do this both sources of infection have to be eliminated: first, a worm-free pasture must be used; second, auto-infection must be prevented.

It is rather difficult in practice to obtain a perfectly clean sward. Although decline of the larval population is rapid for several weeks after removal of all grazing animals, a pasture will remain infective for many months. Few of the common species survive for more than a year [17], and in one instance a pasture sown on land that had carried

sheep 11 months previously appeared to be free from infection [27]. Nevertheless the larvae of some species may survive for anything up to two years, and it is not normally safe to regard a pasture as completely free from all parasitic worm species unless it has carried no ruminant stock for at least that time. A clean pasture is most readily obtained as a new ley, sown after crops that have not been grazed. Grazing the stubble of a wheat crop, for example, must be avoided if a clean ley is required the following year, since ploughing does not necessarily destroy the infective larvae [8, 33].

Starting with a clean sward, it is possible by rapid folding to prevent sheep re-infecting themselves. The animals are moved to a fresh paddock every two days, never return to an area once grazed, and so are one or two paddocks ahead by the time the parasite eggs have developed to an infective stage [30]. The egg-count of a group of sheep managed in this way is graphed in Figure 2, and it shows that the infestation was controlled at an extremely low level with no tendency to increase. This method makes it possible to compare the productivity of sheep at two levels of infection under grazing conditions, and it can be used to keep sheep free from worms at pasture, provided that they are worm-free initially.

It is not yet possible to eliminate all the worms from a sheep once it is infected. Indeed, it would be difficult to determine whether complete elimination had been accomplished, for at extremely low levels of infestation the few eggs present in the faeces may not be detected. A *post-mortem* examination, which is similarly limited by the sensitivity of the techniques used, only provides data about the end-point in the animal's life.

Precisely the same arguments may be applied to any sheep raised worm-free, with the exception that it is easier to detect a new infection in a lamb. The only satisfactory criterion is the continued absence of any eggs in the faeces over a considerable period of time. If a sheep at grass gives no evidence of infection over a period of several months it hardly matters if it does in fact carry one or two worms, for both practical and experimental requirements are satisfied by such an animal.

Since the parasites cannot be eliminated from the infected sheep, it is necessary to start with the new-born lamb. By rapid folding of ewes and their lambs from the time when the lambs are born it has been found possible to raise lambs free from all species except *Strongyloides papillosus*. Lambs raised by folding have sometimes been free from it

but more often pass a very small number of eggs in the faeces. This worm is not regarded as of importance, and it causes damage in sheep only when present in excessive numbers [2]. The reason for the occurrence of this species lies in its rather different life-cycle and habits, notably that it has a free-living generation on pasture and that, being a skin penetrator, it may enter its host by the feet.

Accidental infection may be acquired from several sources, e.g. by lambs grazing through the fence when adjacent to a previously grazed area, and from faeces transported on implements, wild fauna, or the feet of the sheep themselves. Nevertheless, without taking any impracticable precautions, lambs have been reared to weaning time and beyond either worm-free or with completely negligible infections. Because the ewes do not infect the lambs and do not re-infect themselves, the level of infection in the ewe flock is reduced.

One of the most important aspects of these studies of grassland management is their relevance to such problems as the relationship between parasitism and density of stocking with sheep. The fact that worm-infestation can be reduced to negligible proportions by grazing management alone demonstrates that the effect of any increase in the number of sheep per acre will depend largely on the way in which they are managed. The result of the folding method is independent of the rate of stocking. It is therefore meaningless to generalize about the relationship between the rate of stocking and level of worm-infestation except within a given context of management. Similar considerations apply to the relative importance of the ewe and the pasture as a source of infection for the lambs: rapid folding over infected pasture would place the emphasis on the sward; a fortnightly move across clean pasture would place the emphasis on the ewe.

The folding method of management has been developed primarily for experimental reasons. Where the productivity of sheep is used as an index of pasture value, it is essential to know what effect their parasitic worm-burden is exerting. From a parasitological point of view it is necessary to have worm-free sheep under grazing conditions in order to measure the effect of worms in such a way that the results may be applied with validity to agriculture. To a limited extent these purposes are served if sheep can be kept worm-free over an experimental period. This can be ensured by the folding technique, and it is by the use of such



FIG. 5. Infected sheep, showing shedding of the fleece.

methods that the results given earlier in this article were obtained.

The practical implications, however, cannot be ignored. Firstly, management can control the rate of re-infection even on pasture that is not completely worm-free, e.g. one rested from grazing for six months; it therefore provides a means of control at critical times—times when the rate of re-infection is normally very rapid. Secondly, it may be employed in fat-lamb production to ensure the maximum rate of live-weight gain over the 3–4 months necessary to achieve the desirable weight and condition. The value of such methods is ultimately a question of economics: whether the increased production justifies any increased labour or fencing costs.

REARING WORM-FREE SHEEP

Management may also be regarded as a means of rearing a worm-free breeding unit. Theoretically it should be possible to do this by rearing lambs worm-free (by folding) and weaning them on to clean pasture. Ewe lambs could then be retained for breeding. This has not yet been achieved in practice. The success of this approach depends entirely on whether worm-free sheep will

remain so on clean land, and the practical difficulties involved in raising worm-free lambs apply even more to this situation. Any physical transfer of infected faeces to the worm-free area might initiate the normal process of re-infection. In addition, such operations as dipping and shearing might necessitate the removal of the sheep from the worm-free area. It is probable that on an experimental scale these difficulties could be overcome. At the Grassland Research Institute a few lambs have been kept free from infection for a period of several months when weaned on to a clean area; but these were set-stocked on small areas adjacent to paddocks occupied by infected sheep. A further difficulty is how to be certain that a group of lambs weaned on to a clean area does not include one or two animals that have acquired an accidental infection. Since the only adequate test of these cases is to observe their *subsequent* egg-count, this difficulty is a serious one. Various solutions suggest themselves as a first step in the direction of a worm-free flock. Lambs could be segregated into small groups at weaning time, so that the risk of all becoming infected from the one or two carrying unsuspected parasites is minimized. A nucleus of ewe lambs could be raised

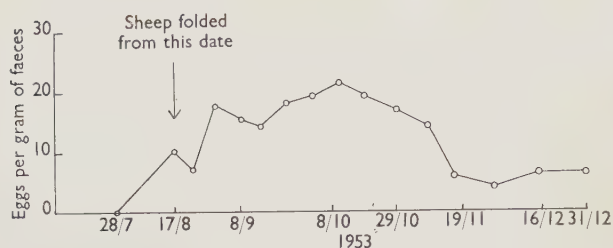


FIG. 6. Control of worm-infestation by folding. (All species except *S. papillosus*.)

indoors under stringent conditions designed to preclude infection.

A worm-free breeding unit would be of tremendous value experimentally. From a practical point of view, however, the enterprise would be subject to continual risk, particularly in the early stages of development. In any event, it is hard to visualize except in a self-contained flock. Recognition of the difficulties involved does not in any way reduce the value of attempts to explore the possibilities. Indeed, the presence of appreciable risk underlines an important question where *any* risk is involved. Three questions, in fact, should logically be asked in considering the concept of a worm-free flock: Is it possible? Is it practicable? Is it desirable? The first two have been answered as far as it is possible to do so at the present time. The third involves a consideration of the phenomenon of resistance. Where lambs are raised free from worms in the field there are always two opportunities for infection. One is when animals being folded have to be moved to an infected pasture, and this may arise either through miscalculation of the area of clean pasture required to carry the flock until weaning time or through poor pasture growth due to adverse climatic conditions. The other is accidental infection, and it is essential to know what effect this will have on sheep previously worm-free and therefore lacking in acquired resistance.

There is no doubt that lambs exposed to infection when quite young develop an acquired resistance to subsequent infection [9]; but the initial infection can be too small to stimulate resistance, and if it is great enough to impair health it can operate in the reverse direction and increase susceptibility. It is consequently very difficult to induce resistance artificially or by management. Furthermore, practical exploitation would require an immunity to the species likely to be encountered, preferably one of some permanence. The normally infected lamb may not have an acquired resistance of a kind or degree that will confer out-

standing advantages. On the other hand, it is by no means certain that an animal reared free from infection will suffer because of a lack of such protection. Evidence to the contrary is that sheep maintained worm-free until one year old suffered no more when exposed to a light infection than similar animals which had previously been infected [28], and a like observation was made with sheep of 8½ months of age. Much depends upon the age of the animal and the degree of infection to which it is exposed; but it appears certain that worm-free lambs do not necessarily suffer to a greater extent, whatever their age, provided that they are not exposed initially to very high levels of pasture infection.

Should an accidental infection occur when the lambs are under four months and still being folded, management can prevent any building up of the infestation established; but when weaned lambs are involved, without folding, re-infection is possible. In general the results of accidental infection need not be serious, and animals of eight months or over do not lose any of the production gained by virtue of their freedom from infection during the preceding months.

The desirability of a worm-free flock, therefore, does not appear to be impaired by considerations of resistance. The advantages from the point of view of production are obvious from the experimental results already quoted. In addition, the worm-free animal enjoys an improved condition of health and well-being. For instance, among lambs grazed on a predominantly white clover sward, no scouring occurred in a group that was practically free from infection (average egg-count = 13 e.p.g.), whereas in a group that had been infected by grazing for 3½ days on a pasture previously grazed by sheep (average egg-count = 600 e.p.g.) the incidence of scouring was almost 100%.

The crucial question at the moment appears to be, what are the parasitological consequences of a small source of infection in a group of worm-free sheep not being folded? Here the limits of present investigation are reached, and the question cannot be answered with certainty; yet there is some evidence on which to base tentative conclusions.

STABILITY AT LOW LEVELS OF INFESTATION

In 1955 two groups of twenty lambs were raised by folding across worm-free pasture at the Grassland Research Institute. The lambs of one group were infected at six weeks of age by dosing them

with suspensions of infective larvae cultured from the faeces of their own ewes. The object was to establish infections similar to those the lambs would normally have acquired by grazing with their ewes had they not been folded. At three months of age these lambs were weaned and, three weeks later, placed on a series of worm-free paddocks, each of $\frac{1}{4}$ acre. Four lambs were placed on each—a stocking rate of 16 per acre. They remained thus, without any further management or anthelmintic dosing, until April 1956. The average egg-count of the infected group when placed on these paddocks was 40 e.p.g. The control group included one or two lambs with accidental infections and had an average egg-count of 0.06 e.p.g. when paddocked in July 1955. Fig. 7

shows the subsequent course of their infestations as indicated by fortnightly egg-counts.

It will be seen that the egg-count of the infected group rose rapidly in late summer and autumn and remained fairly high for much of the winter, whereas that of the control group increased little from its initial figure and kept remarkably low until the following spring. The difference is similar to that between the curves shown in Figures 1 and 6, and a comparison with the latter illustrates the effect of management on the egg-count. The present situation is remarkable for its absence of any effort at control. Although the results of this one experiment must be interpreted with caution, they suggest that the initial level of infection—or, more accurately, egg-output—influences the subsequent pattern of re-infection.

The precise environmental conditions associated with these results are important. The high stocking rate under a set-stocking system led to a rapid decrease in herbage, and silage was fed for much of the autumn and the whole of the winter, supplemented from 20th January by a daily ration of $\frac{1}{2}$ lb. crushed oats per head. Thus the animals were not ingesting normal amounts of herbage. It appears likely that conditions on the ground were not conducive to larval development or survival; but this

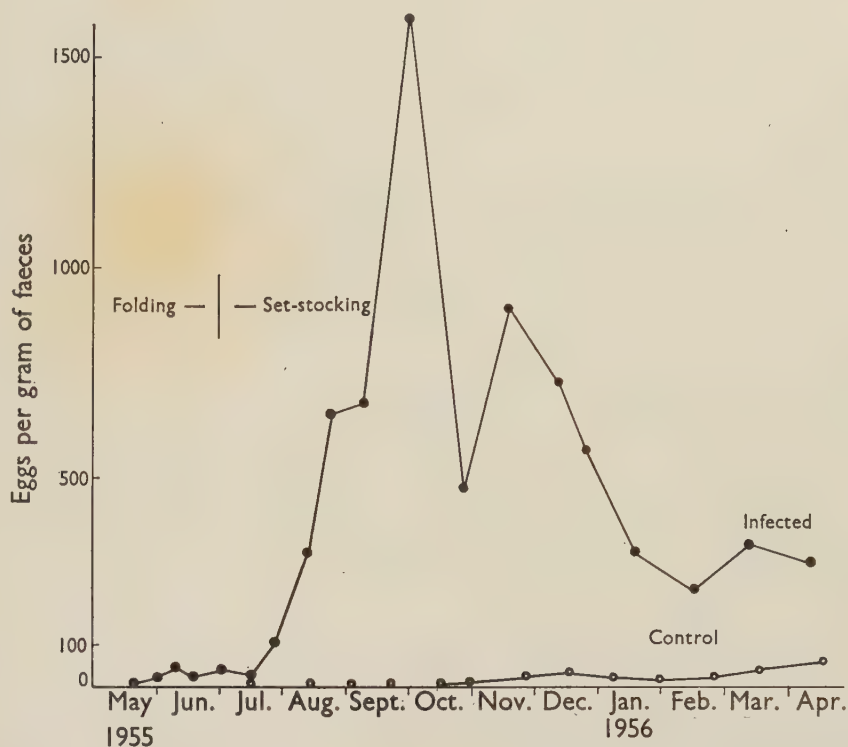


FIG. 7. Average egg-count (all species except *S. papillosus*) of sheep with different initial counts under set-stocking. On each occasion every animal was sampled.

did not prevent the considerable re-infection which evidently occurred in the infected group. The level of nutrition was low during much of the experiment, the infected group suffering much more than the controls. Under these circumstances it is possible that the egg-count for the infected group would be exaggerated as much by the low level of nutrition as by re-infection. The same argument applies to the control group and emphasizes that, in these animals, re-infection must have been negligible. The fact that no significant re-infection occurred, to the extent of producing a level of infestation as low as that obtainable by laborious management, is important, whatever the associated conditions: it supports the view that a high density of stocking does not automatically imply an increased rate of re-infection; it endorses the view that previously worm-free lambs do not necessarily suffer when a source of infection is introduced. An improved nutritional level, an improved management—even a simple rotation—and a lower rate of stocking would only tend to reduce re-infection. An increase in the herbage available would tend to favour larval development and survival. Investigation of the influence of such factors at low levels of infestation should be profitable.

In the experiment described, i.e. within that particular environmental context, a low initial egg-count appeared to be advantageous. The actual count of 0.06 e.p.g. was extremely low, and it is doubtful if such an average count could be expected in pastured lambs except under a folding management over clean pasture. In this instance folding during the critical period before weaning conferred considerable benefit on the lambs over a subsequent period without folding. Whether it would be possible to establish a group of sheep with an initial egg-count so low that a relatively permanent stability of infestation could be achieved is not known. Obviously such a group would have the same advantages as worm-free sheep without, perhaps, sacrificing all resistance and without the difficulties of preventing the slightest accidental introduction of infection.

THE PRESENT POSITION

It is probable that a substantial loss of productivity is sustained owing to worm-infestation of sheep. The importance of grazing management in the control of such parasitism cannot be overestimated. There are two possible approaches to elimination of this problem: complete eradication of the parasites; and control at a level where no appreciable damage occurs. A folding management is flexible enough to achieve either but is attended by practical difficulties which might

render it uneconomic. The attempt to establish a worm-free flock is sufficiently justified for experimental purposes, whatever the practical applications. There is reason to believe that control at a negligible level is possible, but a practicable solution may require a combination of grazing management and anthelmintic treatment based on our knowledge of the pattern of infestation. The chief technical difficulty in exercising such control is that of defining the "tolerance" level in useful terms; attempts have been made to define it in terms of the faecal egg-count, but the actual number of worms could not, in practice, be determined [32]; measurement of the level of pasture infection to which sheep are exposed may be of value, alone or combined with egg-count data.

In conclusion, it is emphasized that the problem is not an isolated one. Control of worm-infestation must not involve practices detrimental to other aspects of sheep management. A real increase in the production of grazing sheep will only be achieved by a synthesis of the knowledge gained from all branches of sheep husbandry.

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THE SYSTEMIC ACTION OF SULPHONAMIDES AGAINST PLANT DISEASES

D. Rudd Jones

Although systemic treatment of disease in plants is still in the experimental stages, a few chemicals have given results of promise. As shown here, some of the sulphonamides readily enter plants via the roots and check infections of such obligate parasites as the cereal rusts, though not without injury to the hosts. Many problems will have to be solved; however, before the gulf between theory and practice is successfully bridged.

In recent years attempts have been made to control plant diseases by systemic treatment, notably with antibiotics and other antibacterials developed for medicine. Among the few chemicals that have shown promise are the sulphonamides, and this paper discusses experimental work indicating their possible value in plant protection.

In 1938, only three years after the discovery of the efficacy of the sulphonamides against bacterial infections in man, Hassebrauk [7] showed that, under greenhouse conditions, o- and p-toluene sulphonamide would markedly reduce rust on the leaves of wheat. The compounds were added to the soil in which the plants were growing and the plants were inoculated with the appropriate disease organism a few days after treatment. These results were soon confirmed by others, but field trials were not successful [6, 18].

After the war, Hassebrauk [8-10] resumed work with the sulphonamides and he was able to control *Puccinia triticina* Erikss. on wheat, *P. simplex* (Körn) Erikss. and Henn. on barley, *P. coronata* Corda on oats and *P. dispersa* Erikss. and Henn. on rye, using the same method of treatment. About the same time other workers [11, 12, 14] showed that sulphonamides sprayed on the leaves of wheat plants two days after inoculation had some eradicant properties, provided that penetration was assisted with wetters. By dissolving Sulphamerazine in a 1.0% solution of Tween 20, Hotson [12] was able to control stem rust of wheat (*P. graminis tritici* Erikss. and Henn.) at the equivalent of 14 lb./acre whereas 80 lb./acre was required in the absence of a wetting agent.

The first successful use of sulphonamides against a cereal rust (*P. graminis tritici*) in the field was made by Livingston (1953) in Nebraska. Using a low-volume spray he applied Sulphanilamide at 1.85 lb. in 5 gal./acre from an aeroplane. Since the chemical was only slightly soluble, it was dissolved first in a small amount of acetone and then made up to volume with water. Triton X45 was added

as a wetting agent. Livingston considered, however, that the low solubility of Sulphanilamide precluded its effective use by aerial application. Subsequently [1] a limited control of rust on spring wheat and barley and a significant increase in grain yield was obtained by hand spraying the sodium salt of sulphanilic acid at a rate of 6 or 9 lb. in 5 gal./acre. The most successful applications were made one week after tillering and 6 days after flowering.

Some evidence that the sulphonamides may be of value in the treatment of virus diseases lies in claims of the successful control of X disease of peach [17] and of carnation mosaic [19].

In all these trials it had been assumed that the sulphonamides were acting systemically, but this fact was not established until 1955 when Rudd Jones and Wignall [13] demonstrated the uptake and translocation of Sulphanilamide in broad beans. The plants were grown in water culture and were treated with Sulphanilamide at 100 µg./ml. through the roots. After 10 days' treatment it was possible to demonstrate the presence of Sulphanilamide in sap expressed from the leaves on paper chromatograms.

The finding that control of rust diseases with sulphonamides can be reversed by treatment with p-aminobenzoic acid [10] and folic acid [11] indicates a mode of action similar to that claimed for the activity of these compounds as bactericides [20]. The toxic effects of sulphonamides on higher plants also appear to depend on competitive interference with p-aminobenzoic acid and may be reversed by this acid [2, 3, 16].

EXPERIMENTS ON CEREALS AND BEANS

In 1953 study began at the Akers Research Laboratories on the movement of sulphonamides in higher plants and the effects of these chemicals in disease control. Oats, wheat and broad beans have been raised in water culture and treated with various sulphonamides through the roots. The

young plants are inoculated with their appropriate rusts, and when the diseases have developed the infection types are recorded and the amount of sulphonamide present in the leaves is determined.

In a typical experiment, oats were raised until the first leaf was fully expanded and, after reducing the waxy cuticle by spraying with 1.0% Tween 20, the plants were inoculated with uredospores of *P. coronata* suspended in a 0.1% solution of the wetter. The plants were then held for 24 hours in a saturated atmosphere at 25°C before being returned to the greenhouse. Three days after inoculation the nutrient was replaced by sulphonamide solutions. Four days later the rust infection types were recorded (Fig. 2), and sulphonamide in the leaf sap was determined by extracting it with 0.5N HCl, precipitating the protein with trichloroacetic acid, and measuring in a spectrophotometer the colour which develops after diazotization and coupling [4]. From the results recorded in Table I it is apparent that there is a relation between the amount of sulphonamide present in the leaves and control of disease. Sulphaguanidine, which is poorly translocated, does not control the disease; Sulphanilamide, which reaches high concentrations in the leaves, does.

Distribution of sulphonamides in the various parts of the plant has been followed more closely in broad beans in connection with the control of bean rust (*Uromyces fabae* (Pers.) de Bary). During the early stages of uptake from a 100 µg./ml. treating solution, the concentration of sulphonamide in the whole plant is a linear function of the water transpired. This relation holds for Sul-

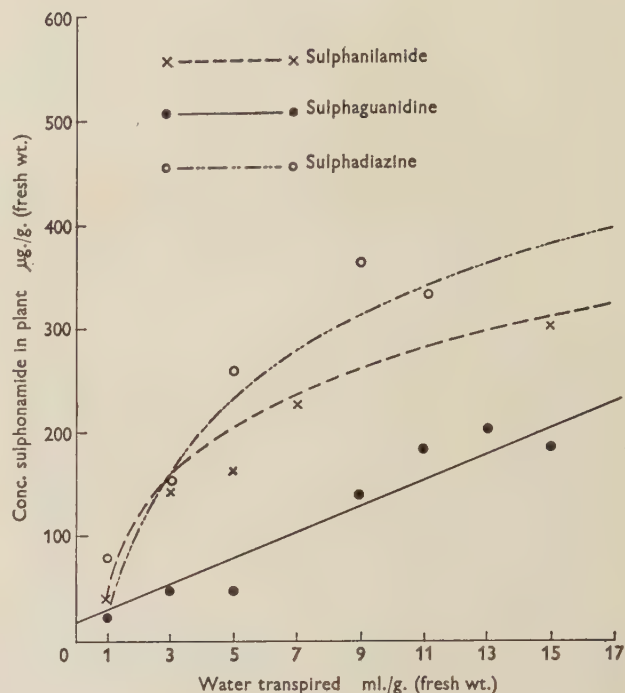


FIG. 3. The relation between water uptake and concentration of sulphonamide in broad beans treated through the roots at 100 µg./ml. sulphonamide.

phaguanidine for up to 10 days' continuous treatment under normal greenhouse conditions. With Sulphanilamide and Sulphadiazine, however, the increase of sulphonamide in the tissues over a ten-day period was found to be a logarithmic function of the water transpired (Fig. 3). Whether the steady reduction in the rate of uptake of these compounds is caused by saturation of the tissues, breakdown

in the plant or phytotoxicity, is not yet known. Sulphaguanidine and Sulphadiazine tend to accumulate in the roots whereas Sulphanilamide moves rapidly into the leaves (Fig. 4). The rate of accumulation in the stems is similar for all three compounds and falls after 13 days. As with oats, differences in the rates of movement into the bean leaves are reflected in the control of *U. fabae*: Sulphanilamide is very effective, Sulphadiazine less so, and Sulphaguanidine does not control the disease at all.

For a systemic fungicide to be successful in the field, it must persist for long periods in the plant

TABLE I

CONTROL OF RUST DISEASE OF OATS (*Puccinia coronata*) WITH SULPHONAMIDES AFTER 4 DAYS' ROOT TREATMENT

Concentration of treatment µg./ml.	Concentration in expressed sap µg./ml.			Rust infection type*			
	50	100	200	50	100	200	Control untreated
Sulphanilamide..	113	253	614	0-4	0-3	0-1	4
Sulphaguanidine	0	17	167	4	4	4	4
Sulphadiazine ..	38	93	206	3-4	0-4	0-3	4

* 0 signifies resistant infection type; 1, 2, 3, 4 signify increasing susceptibility of infection type.



FIG. 1. *Uromyces fabae* on broad beans. Top: Leaf of untreated control plant. Centre: Leaf of plant treated with 100 $\mu\text{g./ml.}$ of Sulphanilamide. Foot: Leaf of plant treated with equal concentrations (10^{-3} M) of Sulphanilamide and *p*-amino-benzoic acid.



FIG. 2. *Puccinia coronata* on oats. Left: Leaf of untreated control plant. Centre and right: Leaves of plants treated with 100 $\mu\text{g./ml.}$ Sulphanilamide.

in an active form. Trials were therefore carried out in which broad bean plants were treated through the roots at 100 $\mu\text{g./ml.}$ Sulphanilamide for four days. The plants were then transferred to nutrient solutions and the amount of sulphonamide present was determined after various time intervals. Seven days after stopping treatment 60% of the Sulphanilamide taken up could be recovered from the plant and thirteen days after, 40%. In addition, 25% of the Sulphanilamide taken up had leached out from the roots by this time. Rust infections developed

subsequently on these plants, indicating that the Sulphanilamide was acting as a fungistatic rather than as a fungicidal agent.

Detoxification of sulphonamides by acetylation of the free amino group, which is known to occur in animals [5], has recently been demonstrated in the roots of broad beans [13]. Since the acetyl derivative is not fungistatic it follows that, if Sulphanilamide is to be used as a systemic fungicide, quantitative allowance will have to be made for this chemical change.

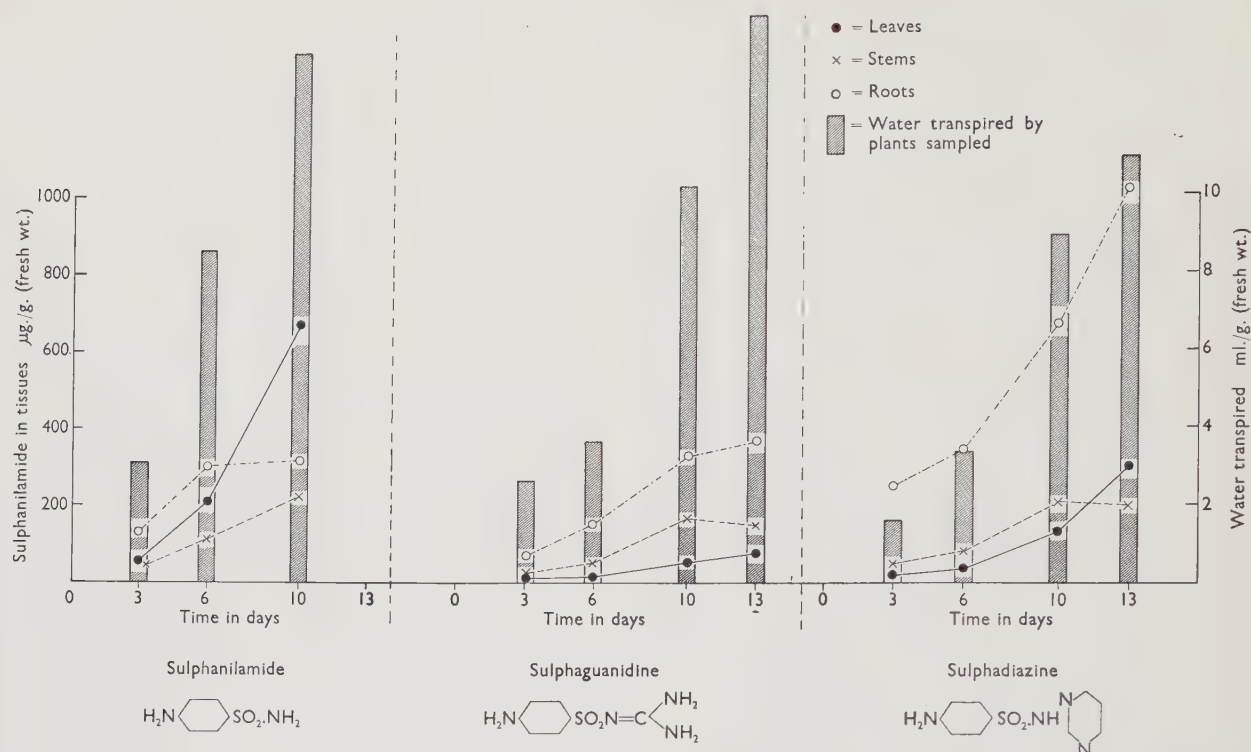


FIG. 4. The distribution of sulphonamides in broad beans treated through the roots at 100 µg./ml. sulphonamide.

Sulphonamides have been used successfully to control mildew on oats and wheat (*Erysiphe graminis* DC) and mildew on cucumber (*E. cichoracearum* DC) by treating the plants through the roots at the time of inoculation or shortly after. But against a number of facultative parasites, using a similar method of application, they have been quite ineffective. In preliminary *in vitro* tests the chemicals proved to be both bacteristatic and fungistatic: Sulphanilamide was more effective against fungi; Sulphadiazine and other heterocyclic ring substituted compounds were more active against bacteria. In the host plant, however, no control of disease symptoms was obtained. The diseases studied have included soft-rot of potato and tomato (*Erwinia carotovora* (Jones) Holland), halo-blight of dwarf bean (*Pseudomonas phaseolicola* (Burkholder) Dowson), halo-blight of oats (*Ps. coronafaciens* (Elliott) Stapp), black rot of cabbage (*Xanthomonas campestris* (Pammel) Dowson), chocolate spot of broad bean (*Botrytis fabae* Sard.), and blight of tomato (*Alternaria solani* (E. and M.) Jones and Grout).

Injury to the host plant is a serious problem in the use of Sulphonamides, particularly with sulphanilamide which would otherwise be the most effective fungicide of the group. It is probable that

TABLE II

TOXICITY OF SULPHONAMIDES TO TOMATO PLANTS AFTER 7 DAYS' ROOT TREATMENT AT 100 µg./ml.

	Fresh weight of treated plants as a percentage of fresh weight of untreated plants
Sulphanilamide ..	58
Sulphacetamide ..	66
Sulphaguanidine ..	90
Sulphadiazine ..	107
Sulphathiazole ..	78

the high phytotoxic effect is a consequence of high mobility of the compound within the plant. Normal symptoms of damage are stunting of root and shoot, chlorosis, necrotic lesions on the leaves, and a marked drop in fresh weight (Table II). The toxic effect on broad beans (and also on the rust infection) has been reversed by adding p-aminobenzoic acid to the treating solution at equimolecular concentrations to the sulphonamide (Fig. 1). Although in antibacterial studies one molecule of p-aminobenzoic acid will reverse as many as 2000 molecules of Sulphanilamide, in the plant much higher concentrations must be applied to the roots

because p-aminobenzoic acid moves very slowly through the tissues.

DISCUSSION AND CONCLUSIONS

With the data now available it is possible to examine the sulphonamides critically as potential systemic fungicides. For a fungicide to be successful systemically certain conditions have to be fulfilled:

1. It must enter the plant and move freely to the diseased areas.
2. It must be highly specific in its action so that the parasite is killed or checked without harm to the host.
3. It must persist in the host for long periods in an active state.

Do the sulphonamides satisfy these requirements? They enter the plant and in certain cases move rapidly to the diseased area when applied to the roots; but because the chemicals are likely to be degraded in the soil they may have to be applied to the foliage if they are to be effective in the field. A further limitation is that the sulphonamides have proved successful only against obligate parasites. If they are to be used against facultative parasites—and they have *in vitro* activity against several of these organisms—treatment must begin well in advance of infection so that

concentrations can build up in the peripheral parts of the plant sufficient to check the development of disease. This means that the sulphonamides will probably fail on the second requirement, for the concentrations reached will almost certainly be toxic to the host by the same mechanism of p-aminobenzoic acid antagonism. The sulphonamides are not specific enough in their action, and concentrations in the leaves as high as 100 µg./g. fresh weight are required to check germination of uredospores. Experiments so far carried out indicate that sulphonamides will persist for long periods in plants, but the proportion that remains in the active form has not yet been ascertained. There is the very strong objection that they are only fungistatic so that, very shortly after treatment is stopped, checked infections may develop again.

Despite these drawbacks, the sulphonamides are of great experimental interest because of their systemic activity against obligate parasites, particularly rust diseases of cereals the control of which has always been based on the breeding of resistant varieties. With the appearance of new physiological races of cereal rusts, and the lower yields to be expected from the varieties that must be continuously bred to combat them, the plant pathologist is now turning to chemical means of control.

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SURVEYS OF DISEASE IN DAIRY CATTLE IN GREAT BRITAIN

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Lack of reliable information on the incidence and effects of diseases of farm animals makes it difficult to assess the magnitude of any particular problem and the amount of research to devote to its solution. The remedy is to establish systems for collecting and analysing data on a national scale. In Britain survey work begun in 1950 is already providing valuable material on the relative importance of infections in our dairy herds.

The need for accurate statistics on wastage and the incidence of disease in domestic livestock has been recognized for many years. Such information is of great importance to the agricultural industry and veterinary science, for an enormous amount of loss occurs every year and in every country from mortality, from the culling of animals rendered unproductive by disease and from temporary loss of production through sickness. Although accurate and detailed information is available from official sources in most developed countries on notifiable diseases, such as foot-and-mouth disease, tuberculosis, anthrax and swine fever, the non-notifiable diseases of everyday occurrence, which in the aggregate cause large losses in money and stock, have not been statistically recorded. Yet we investigate these diseases and attempt to control them without full knowledge of their actual extent or of the factors influencing their occurrence—information that would be invaluable in directing research along the best lines and in assessing the merits of therapeutic and control measures.

This need has been felt in many countries. In America, for example, as long ago as 1920 the U.S. Livestock Sanitary Association recommended each State to take steps to gather reliable information concerning the health of livestock, and in 1945 it advocated the establishment of a Division of Vital Statistics in the Bureau of Animal Industry [2]. In spite of such pressure a national reporting agency has not yet been established, and although several States are at present operating disease reporting systems these are not on entirely standardized lines. Only recently has the U.S. Agricultural Research Service taken up the task of determining what measures can be adopted to establish a nationally co-ordinated reporting system.

In Great Britain the need has been equally felt. Estimates of the ravages of disease in livestock were compiled by the Survey Committee of the National Veterinary Medical Association in the

early part of the 1939–45 war, and a great deal has been done since in the control of the major diseases affecting farm livestock. There have been many investigations into specific diseases, and surveys on a limited scale of diseases in particular species or classes of livestock. Nearly all such work has suffered from certain disadvantages: the herds or flocks studied have usually been samples chosen on account of willingness to co-operate or convenience of location rather than at random; work has been confined to particular areas and limited periods of time; co-ordination between different agencies has often been lacking. Attempts to correlate the information collected by different people at different times and places demonstrate that a planned scheme and standardized methods are essential if progress on a wide scale is to be achieved. Some widespread diseases, such as mastitis, abortion and infertility due to brucellosis and vibriosis, and Johne's disease, although not officially notifiable, have undoubtedly stimulated a great deal of research leading to practical methods of treatment and control, but it in no way detracts from the value of such work to plead for a co-ordinated system for the collection of vital statistics on animal disease on a national basis.

INITIATION OF THE WORK

In 1949 the N.V.M.A. [1] made an attempt to institute a nation-wide survey of diseases in our herds and flocks by inviting veterinary practitioners to enlist a cross-section of their clients to keep records under veterinary supervision, but the response was not encouraging and it was soon apparent that some centralized agency, preferably with whole-time staff, would probably be necessary if it was to succeed on a sufficiently large scale and continue for a period of years.

This effort, however, was not wasted. The method proposed by the Association was adopted

basically when, in the following year, the Veterinary Laboratory at Weybridge initiated a pilot survey of dairy herds in a limited area to test its practicability. Subsequent developments have largely been due to the support and encouragement of the Director, Dr. A. W. Stableforth, who has long been associated with pioneer work in this field. The work carried out since 1950 is to be regarded as operational research to investigate survey technique and assess the value of the data obtained.

The survey began in Surrey and Berkshire in 1950-1 and was extended to Wiltshire in the following year. Several herds in the original samples have fallen out annually, but about one-third of them have kept records for five or six years. No new herds have been recruited in Surrey and Berkshire, but in Wiltshire fresh samples were added and surveyed in 1953-4 and 1954-5.

In 1953 the Agricultural Research Council provided funds for a research officer to carry out a similar survey in Devonshire. This worker has also examined knackery material with laboratory assistance from the regional Veterinary Investigation Centre, and this will undoubtedly yield accurate information on the incidence of diseases responsible for culling in dairy herds. In the same year assistance received under the Conditional Aid Scheme for the use of funds derived from U.S. Economic Aid permitted the appointment of three additional research officers and extension of the survey to Shropshire, Ayrshire and Lanarkshire in 1954-5 and to the West Riding of Yorkshire in 1955-6. Although it has not so far been possible to carry out a survey on a national scale, work has now been initiated in five well-distributed and representative areas, with over 600 herds being surveyed in the current year.

Much thought has naturally been devoted to methods of carrying out surveys. Experience has shown that attempts to collect data either through practising veterinary surgeons or lay recorders fall down in practice. The busy practitioner cannot spare time to record the detail necessary for adequate analysis, although he will readily co-operate in other ways with a recording agency. On the other hand, the collection of data on disease by laymen may lead to serious inaccuracies and be resented on professional grounds, and lay recorders do not inspire the confidence of herd-owners—a very important consideration in this type of work. It is therefore felt that the recorder should be a veterinary surgeon with some expe-

rience of practice and of research methods who can visit the farms regularly and draw sound conclusions from the information recorded. In these surveys the practice adopted was to issue a record card to the herd-owner or stockman as recommended by the Technical Development Committee of the N.V.M.A. Only the farmer knows what happens to every animal, and if he can be induced to write down these events half the battle has been won, for his record will form the basis for questioning and enquiry.

Attention was focused on the subject of disease surveys of livestock at the 73rd Congress of the British Veterinary Association (formerly the N.V.M.A.) at Belfast in 1955. A session was devoted to Vital Statistics in Veterinary Medicine, and papers were presented on the incidence of disease in cattle, sheep and pigs and on a survey of veterinary practice [2, 4, 8]. This led to informal meetings of those interested, and it is now generally agreed that the ultimate objective should be to provide regular statistical information by means of a national survey, either annually or periodically, on similar lines to those employed during the past few years.

HERD SAMPLING

During the first three years of this survey the aim was to recruit 5% samples of dairy herds in Surrey, Berkshire and Wiltshire. The Surrey sample was based on a Weybridge mastitis survey, and those for the other counties were obtained by taking 1 herd in 20 from the lists in the Animal Health Divisional Offices. Owing to the poor co-operation of non-designated herds and inclusion of herds (mostly attested) selected by veterinary surgeons under the N.V.M.A. scheme, samples tended to be overweighted in favour of the designated herds. This was accentuated in succeeding years, for most of the designated herds continued in the scheme, whereas an increasing number of non-designated herds dropped out.

In 1952 Mr. F. B. Leech of the Department of Statistics, Rothamsted Experimental Station, took over the work of sampling. He recommended that fresh random samples of herds should be drawn each year and that a small number (25-30) of the original herds should be retained for several years to indicate seasonal variations in disease incidence. It was decided to continue to survey the herds willing to co-operate in the three counties and to apply the new procedure to further samples in Wiltshire and in any areas to which the work

might be extended. The method adopted from 1953-4 on has been as follows. Random samples of designated and non-designated herds* are drawn by the Milk Marketing Board from its lists of registered milk producers, herds are classified according to the numbers of dairy cows they contain, and sampling fractions are applied to the size-groups. The fractions are chosen to give the numbers of herds required in the final samples, usually omitting the smallest herds and including relatively more of the larger herds, which, though less numerous, frequently contain a large proportion of the cattle population and would often not be adequately represented if a single fraction were used.

By drawing samples in this way the results in each stratum can be multiplied by the reciprocals of the relevant fractions to provide estimates of the disease incidence in the sampling areas. In Table I an example of this procedure is shown.

Some samples are drawn from whole counties; others, particularly in dairying areas, are selected according to the distribution of farming types. Sizes of the samples have primarily depended on the number of herds that could be adequately visited and recorded by the staff available. On average, one person can deal with 100-150 herds.

RECORDING TECHNIQUE

Information for his herd is recorded by the farmer or stockman on a large "Farmer's Card," of which one type is provided for 25 cows and young stock and another for 40 cows. Entries include the names or numbers of cows, dates of

calving and service or insemination, and details of deaths, disposals and sickness during the survey year. The numbers of young stock and any sickness among them are also noted. These cards normally suffice for one year, and the survey year starts on 1st October to coincide with the milk-recording year.

Since 1952 punch cards of two kinds have been used instead of plain cards for transcribing data from the farmers' cards. Particulars relating to the herd as a whole are recorded on a "Farm Card," e.g. numbers of stock, breeds, fertility status (indicated by the numbers of services or inseminations required for the year's calvings), number of dry cows in each month, information on pasture, milking technique, and use of S.19 vaccine. On the reverse of this card is a summary of the calvings under months and lactation numbers. An "Individual Card" is used for each cow or served heifer that dies, is disposed of, or is sick during the survey year, only one card being made out for a given animal, irrespective of the number of attacks of disease during the year. Particulars of age, breed, last calving date and subsequent service dates, date of death or disposal with cause, and the destination of the carcass or animal are entered. On the reverse side are noted details of each attack of sickness with dates of onset, duration and outcome.

Visits are paid to the herds at approximately quarterly intervals for the recording of data and numbers of stock in the categories: bulls, cows, served heifers, yearling heifers, heifer calves, bull calves and other cattle. The total average stock of each category for all herds in the sample gives the population on which disposal and disease incidences

TABLE I
SAMPLING PROCEDURE: WILTSHIRE, 1953-4

Class of herd	Total herds	1st stage sample					2nd stage (final) sample					
		Sampling fraction	No. of herds				Sampling fraction			No. of herds		
			1-9 cows	10-25 cows	Over 25 cows	Total	1-9 cows	10-25 cows	Over 25 cows	10-25 cows	Over 25 cows	Total
Non-designated ..	1174	1/10	24	70	32	126	0	2/7	1/1	20	32	52
Designated ..	1926	1/20	6	28	65	99	0	2/3	1/2	18	33	51

* Since the Accredited Herds Scheme came to an end on 30th September 1954 only Attested and/or TT-licensed herds are "Designated."

are calculated. Data are analysed by the Statistical Department of Rothamsted Experimental Station.

PRACTICAL DIFFICULTIES

A fundamental difficulty is to obtain the full co-operation of herds drawn in the samples. So far the degree has varied from 70 to 90% and has been lowest among owners of non-designated herds. In areas where progress towards attestation has been rapid, herds drawn as non-designated often become attested or are in the process of attestation when they are first visited, and co-operation may be refused because changes in herd composition make record-keeping difficult. If such herds have already become attested and the owners are willing to keep records, the balance of the sample is upset. For herds that are still non-designated at the time of recruitment but obtain TT licences or become attested during the survey year, the date of change of status is noted and the herds are regarded as being of the designations held for the greater part of the year. "Flying" herds introduce a difficulty in that the cows are constantly being changed and a large turnover is involved in maintaining a herd of moderate size; there is thus an abnormal number of disposals, augmented by a tendency to cull sick animals, so that information is unreliable even if ascertainable.

Refusals to co-operate on grounds of overwork, ill health and the like are inevitable, and owners of large pedigree and attested herds who rear stock for sale are often loath to record their troubles in writing. On the whole, however, the response is good, for the scheme is voluntary and the farmer gets no material return for his extra work.

Undoubtedly the ideal type of herd is the self-contained and attested herd in which, apart from normal wastage through deaths, old age, poor yield and infertility, the cows remain in the herd for their normal life-span and replacements are made from young stock reared on the farm. In such herds it is comparatively easy to record wastage and disease accurately, and owners are usually willing to do so. Unless it can be shown, however, that such herds give a picture of disease incidence similar to that for other types in the area the results cannot be used to estimate total loss or average incidence.

Standards of record-keeping vary from the almost perfect to the primitive, for no arbitrary standard of efficiency has been laid down. But it is very desirable to secure the maximum amount of reliable information, and much has to be done by

questioning sketchy records. Willingness to co-operate is encouraged.

RESULTS ACHIEVED

Results of the pilot survey in the first two years have already been described [7], and those for 1952-3 and 1953-4 and information from later samples will be published shortly. Here it is proposed to give in broad outline the results obtained during the first four years and to make some observations on the analysis of this material.

Deaths and Disposals

These have been classified in seven categories: deaths, old age, infertility, poor yield, disease and accident, reactors to tuberculin, and surplus disposals. The first six represent herd wastage inasmuch as the majority of the animals disposed of go for slaughter and are lost to the dairy industry. The last consists of sound animals surplus to requirements, and the figures recorded will therefore depend on the proportion of herds in a given sample which regularly dispose of sound stock at markets and sales. In Table II deaths and disposals are shown as percentages of the total cow populations in each sample.

TABLE II

DEATHS AND DISPOSALS AS PERCENTAGES OF THE TOTAL COW POPULATIONS IN HERDS SAMPLED IN SURREY, BERKSHIRE AND WILTSHIRE, 1950-1 TO 1953-4

Years	1950-1	1951-2	1952-3	1953-4
Counties	Surrey Berks	Surrey Berks Wilts	Surrey Berks Wilts	Surrey Berks Wilts
No. of herds	122	163	170	132
Total cows	3452	4966	5984	4879
<i>Category</i>				
Deaths	1.5	1.3	1.1	1.2
Old age	1.6	2.6	1.8	1.2
Infertility	4.4	4.1	3.5	2.8
Poor yield	4.4	5.0	6.3	5.7
Disease and accident	3.5	3.8	4.4	5.1
Reactors	4.5	1.6	1.0	2.7
Wastage	19.9	18.4	18.1	18.7
Surplus	7.1	4.0	4.8	3.3
Total deaths and disposals	27.0	22.4	22.9	22.0

These figures are reasonably consistent and indicate little change in the picture of disposals during the four-year period. Wastage on account of infertility appears to have decreased slightly and that from poor yield and sickness to have increased. Owing to the frequent disposal of animals for more than one reason the categories tend to overlap, and records kept of such cases from 1953-4 onwards show that approximately 10% of disposals are of this kind. For purposes of classification, however, these have been allotted to the category regarded as the more important. In 1950-1 there was considerable removal of reactors from the accredited and non-designated herds in Surrey and Berkshire during progress towards attestation, and this was again evident in all three counties in 1953-4; but, excluding those disposed of solely on account of reaction to the tuberculin test, wastage rates in the four successive years were 15.4, 16.8, 17.1 and 16.0%. Comparison may be made of these figures for disposals with a summary of published information collected by Wright [9] in 1933 for Scotland and a number of counties in England, and with herd wastage figures published by the New Zealand Dairy Board [5].

TABLE III

DISEASE CONDITIONS AS PERCENTAGE CASE INCIDENCES IN HERDS SURVEYED IN SURREY, BERKSHIRE AND WILTSHIRE, 1950-1 TO 1953-4

Disease condition	1950-1	1951-2	1952-3	1953-4
Difficult calving	2.0	1.6	1.4	1.5
Stillbirths (over 270 days)	3.6	4.1	3.3	3.1
Abortions (up to 270 days)	3.2	3.0	2.4	3.3
Retained placenta	3.3	2.5	2.5	2.3
Milk fever	2.8	1.6	2.5	3.7
Mastitis	7.9	6.6	9.7	11.5
Summer mastitis	0.2	0.5	0.4	3.0
Digestive disturbance, incl. winter scours ..	5.0	2.2	4.3	2.6
Foul foot	3.7	1.4	1.4	1.2
Accidents and injuries ..	3.2	2.0	1.8	2.5
Respiratory disease, incl. husk	0.6	2.8	1.0	1.2
Johne's disease	1.0	0.8	0.9	0.8
Acetonaemia	0.8	0.7	0.6	1.2
Bloat	0.6	0.7	0.5	1.0
Grass tetany	0.1	0.5	0.4	0.5
Genital disease (metritis, leucorrhoea)	0.2	0.9	0.5	1.2
Miscellaneous	1.7	1.4	1.8	2.5
Total sickness	39.9	33.3	35.4	43.1

Sickness

Table III gives the incidences of the more important disease conditions recorded in the same samples of herds for the four years. The figures show percentage case incidences, each attack of disease in the survey year being recorded as a case. On an average 1.2 cases per affected animal were recorded. Cases of sickness which resulted in death or disposal are included in these figures.

Some of the more obvious differences from year to year in these figures are almost certainly due to seasonal variations: milk fever was more prevalent in 1950-1 and 1953-4 than in the intervening years; there was a serious outbreak of summer mastitis in 1954, with an incidence at least six times the normal figure; winter scours was commoner in 1950-1 and 1952-3 than in the other years; in 1951-2 husk affected adult cattle in many herds, especially in Berkshire; acetonaemia and bloat were highest in 1953-4. On the other hand, differences may be purely fortuitous. The high incidence of foul foot in 1950-1 is accounted for by an abnormal number of cases in one large herd in Surrey, and the figures recorded in the other three years (viz. 1.2-1.4%) probably represent a fair estimate of the overall incidence. Although cases of genital disease show a general increase from 0.2 to 1.2% in the four years this does not necessarily indicate a true rise in incidence: it may well be due to improved recording in herds that have co-operated during the whole period. A large proportion of the miscellaneous sickness was attributable to teat affections, such as "black spot" and teat obstruction, and to lameness other than foul foot; small numbers of cases of poisoning, wooden tongue, parasitic disease other than husk, pyelonephritis, eye infections and other conditions make up the remainder.

ANALYSIS OF DATA

The data available are too meagre to permit analysis of many of the conditions for which records were obtained. Even such well-known troubles as Johne's disease, acetonaemia, bloat and grass tetany cannot yet be usefully considered, and it is possible only to make a few observations on some of the commoner conditions.

Mastitis

Mastitis, which shows the highest incidence, lends itself to more detailed analysis than other diseases. Some 300-600 cases have been recorded each year, and the incidence appears to have increased

appreciably from 1951-2 to 1953-4. About two-thirds of the herds, containing three-quarters of the cows, recorded cases. In all four years the larger herds were more prone to the disease, the mean sizes of affected and unaffected herds being 37 and 28 cows respectively, compared with a mean for all herds of 33 cows. Incidence also rises considerably with age: based on the numbers of cows in each annual age-group, it appears to increase from about 4% in the first lactation to approximately 17% in the old cows (Fig. 1). With regard

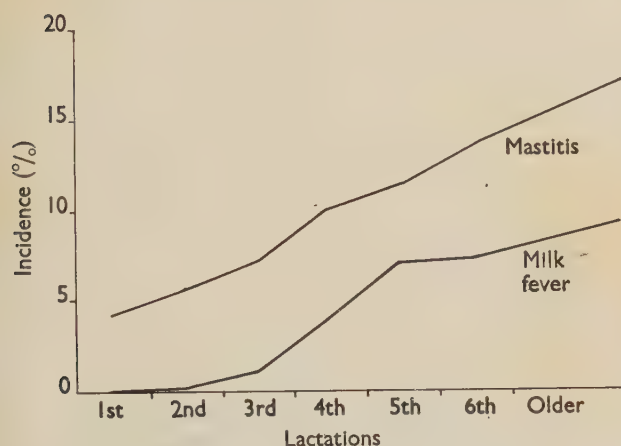


FIG. 1. Mean incidences of mastitis and milk fever for the 4-year period, 1950-1 to 1953-4, in cows of increasing age.

to the relationship of the first attack to the stage of lactation, 30-35% of the cases occur within one month of calving, most of them within a week, and a further 6-12% occur in cows at the end of lactation when drying off or dry. Evidence of any seasonal influence on the occurrence of mastitis is very slight, and prevalence of the disease in late autumn and winter may be related mainly to the pattern of calvings.

Summer Mastitis

Normal incidence of this condition does not exceed 0.5% of the adult cow population. In 1954, when the weather was cool and dull and very wet, a serious outbreak which started late in July and subsided in September may have had some relation to the prevalence of certain flies. Species of *Hydrotaea* were the commonest found on the udders and teats of cows at the time, and *Corynebacterium pyogenes* was readily recovered from them. The end of the period of activity of *Hydrotaea* coincided with the end of the summer mastitis season. There were 148 cases in cows and 21 in uncalved heifers, incidences of 3.0 and 1.8% respectively.

A little less than half the herds reported cases, and again it was the larger herds that appeared to be more affected. The mean sizes of affected and unaffected herds were 45 and 31 cows respectively. Unlike lactation mastitis, the incidence in animals of different ages (except uncalved heifers) showed little variation and ranged from 2.5 to 3.3%. Incidence among the dry cows reached 13.6% in August, and 3.4% of the affected cows died; but there were no fatal cases in heifers.

Difficult Calvings and Stillbirths

These two conditions show rather similar pictures. Nearly half the difficult calvings and nearly 40% of stillbirths occur in first-calving heifers, and the conditions are 2-2½ times as common in heifers as in multiparous cows. This difference is more pronounced in calvings that take place in the winter months, and the question arises whether the explanation is nutritional. It appears that a heifer calving in winter is much more likely to have a difficult parturition or a dead calf than one calving at other times of the year or than older animals. It may be that heifers in calf are often left to run with store cattle and get scarcely more than a maintenance ration. This is well worth further study, and it will be interesting to see if a similar tendency emerges from other samples.

Abortion

In the absence of any precise definition all pregnancies terminated up to 270 days from service or insemination have been classified as "abortions" and the gestation periods recorded. In a survey of this kind it is not possible to investigate causes, but it is known from collateral data that few of the cases are due to *Brucella*. The recorded incidences to 210, 240 and 270 days are 1.5-1.7, 2.0-2.6 and 2.4-3.3% respectively. If "abortions" are limited to cases occurring up to 210 or 240 days the balance of cases would need to be recorded as "premature births," stating whether over 210 or 240 days. Abortion seems to be commonest at the second parturition and then to fade off and to increase again in older cows. As more data become available it may be possible to correlate age of dam with the stage of gestation at which abortion occurs.

Retention of the Placenta

This condition shows an apparently steady rise with age from under 2% in first and second calvings to 4% or more in older animals.

Milk Fever

In certain years milk fever is more frequent than in others, and there is possibly a climatic explanation. Incidence increases markedly with age. Cases are very rare at first parturition and uncommon at second calving. From an incidence at third calving of about 1% it rises to about 9% in cows that have had six calves or more (Fig. 1). There is also a marked seasonal effect, with much higher incidences in calvings from May to October than at other times of the year.

Digestive Disturbances

Ordinary digestive troubles (indigestion, digestive chill, traumatic gastritis, etc.) have remained fairly constant with incidences of 1.5–2.0%. Winter scours, which accounts for the larger incidences in 1950–1 and 1952–3, affects very few herds in any one year; but incidences in the affected herds have been 15% to nearly 30% of the cows, and in about a third of the herds affected it may reach 100%.

INTERPRETATION OF RESULTS

In interpreting results the degree of reliance that can be placed on the recorded data is of fundamental importance. Aggregate figures for deaths and disposals will be very near the truth, for the only sources of error are in assessing causes of death and reasons for disposal, neither of which affect the figures as a whole. Diagnosis is likely to be sound for such troubles as difficult calvings, stillbirths and abortions, retention of the placenta, milk fever and mastitis; but other conditions, particularly diseases such as acetonæmia, grass tetany, and ill-defined sickness that is not seen by a veterinary surgeon, may be less accurately recorded. Some cases, for example "indigestion" and "chill," which may or may not have been attended professionally, can be difficult to diagnose correctly, even if the services of a laboratory are available. No method that is both practicable and reasonably economical will produce absolutely accurate data. Nevertheless it may be assumed

that, for all practical purposes, the method used in this survey gives reasonably reliable information on the chief causes of wastage and on the incidence of the more important diseases.

Another factor in interpretation is the proportion of herds in the samples in which cases of any given disease are recorded. In so far as the object is to obtain data on the relative importance of different diseases in the area surveyed, overall incidences are of value; but if it is desired to correlate disease with environmental factors, the proportion of herds affected assumes importance. It has therefore been suggested that it would be useful in analysing data to give the percentage of herds in the sample in which cases of the various diseases occur, and the incidence in the affected herds, as well as the overall incidence. For most of the diseases recorded from one-quarter to two-thirds of the herds in a sample may be affected. A rather extreme example already referred to is winter scours: it affected only 6% of herds, having an overall incidence of 1–2%, yet its incidence in affected herds was sometimes total.

The results discussed in this article relate to less than one-third of the material that will be available when the current year's surveys are completed. It is confidently hoped that a good deal more useful information will be forthcoming when the present phase of the work is completed.

SUMMARY

The need of accurate statistics on the incidence of disease in farm livestock is emphasized. An account is given of a survey of dairy herds in various parts of Great Britain which has been carried out by the Veterinary Laboratory, Weybridge, since 1950. The development of the work during the past six years and the sampling and recording techniques used are described. Some practical difficulties associated with such surveys are mentioned. The wastage and disease incidence recorded in samples of herds in Surrey, Berkshire and Wiltshire during the four years 1950–51 to 1953–54 are summarized and the analysis and interpretation of the data discussed.

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BOOK REVIEWS

Agriculture: The Science and Practice of British Farming. J. A. S. Watson and J. A. More. Tenth edition, revised. Pp. 983, with line and half-tone illustrations. Oliver and Boyd Ltd., Edinburgh. 1956. 31s. 6d. net.

Nearly every student of agriculture is liable to find that either "Fream" or "Watson and More" is required reading for examination purposes. It is a pleasure therefore, to review the tenth edition of the latter. The senior author (who now has a number of collaborators) has been successively Professor of Rural Economy at Oxford, agricultural attaché in Washington and Director General of the advisory services. He is thus in a unique position to paint an overall picture of the farming industry in this country.

British farming is indeed fortunate in having textbooks of this kind. There is, for example, nothing of similar calibre in the United States. It is, of course, impossible to cover the whole field in detail, but the introductions to subjects such as soil science or genetics are likely to whet the appetite of the student to look elsewhere for further information.

The book is divided into four parts. The first gives a brief description of soil types, plant growth, manuring and cultivations. This is a good introduction and covers the ground very adequately. In dealing with implements, however, the pruning of material given in earlier editions might have been more drastic. The space given to illustrating horse-ploughs and cultivators might with advantage have been devoted to tractor-mounted implements. Most modern implements are mentioned, but the student might have difficulty in understanding their mechanism from a written description alone. In a later chapter, nine pages are given to a description of the threshing machine (which usually belongs to a contractor) and only one paragraph to the baler (which is more often owned by the farmer). There is also surprisingly little mention anywhere of one of the chief problems of the man starting in farming—the high capital cost of machinery and the economic considerations which should govern the choice of implements. The chapter on weed control is, however, an admirable summary of a new and rapidly developing field.

The next section is well presented and surveys the cultivation, seed varieties and diseases of the principal crops. Occasionally one feels that undue space is given to obsolescent varieties—particularly of cereals, but this is not a subject on which one

can expect a general textbook to be entirely up to date. The chapter on grassland is interesting and contains all the information a student should require. There are occasions, however, when one could wish the author from his wide experience to be more strongly didactic. This is perhaps against the policy of the book which is mainly descriptive, leaving the student to make his choice amongst the alternatives available.

The section on livestock is admirable and the account of the theory of rationing is a model of compression. One minor criticism might be made of the milking parlour on page 643: the arrangement of yards suggests that each batch of cows must be moved three times during milking—a somewhat time-wasting arrangement.

The final section on farm organization is a necessary complement to the rest of the book, for the student must not only learn about crops and livestock but how to co-ordinate them. The summary of farming systems is excellent, but the account of efficiency measures does not add up to a coherent system. In view of the wide diversity of standards offered by agricultural economists (of whom the reviewer is one), it is perhaps unreasonable to blame the author for this.

Minor defects are inevitable in a comprehensive textbook but, on the whole, it can be recommended without hesitation not only to the agricultural student, who probably knows it already, but to any practising farmer who is still young enough to learn better methods.

F. G. STURROCK

Soil Physics. L. D. Baver. Third edition, revised. Pp. xvii + 489, with line and half-tone illustrations. Chapman and Hall Ltd., London. 1956. 62s. net.

As a guide to the very extensive literature of soil physics this third edition has much to recommend it. The author succeeds in summarizing the results and conclusions of a host of investigations, and gives ample references to original papers.

Following a good historical introduction, chapters on the soil as a disperse system, the mechanical composition of soil and the physical behaviour of soil-water systems are rather disappointing in their lack of clear purpose. Even the most attentive reader will find it hard to decide just how much reliance to place on some portions, particularly that concerned with "hydration." The validity of the conventional equation for obtaining "zeta-potential" from electrophoretic migration has

never been established for deflocculated clays. Fact and fancy have got badly tangled together.

The remaining chapters on soil structure, soil air, soil water, principles of soil irrigation, principles of soil drainage, soil temperature, physical properties of soils and tillage, and physical properties of soils in relation to erosion, are more direct in their approach, and generally speaking leave the reader with a fair picture of the present state of our knowledge.

This is not to say that all is as clear as could be desired. For instance there is nowhere a simple statement of the way in which non-capillary pore-space has been determined, although the importance is stressed and results are quoted. There is a rather general failure to relate the definitions of physical properties to the way in which they are determined.

This book is not an outstanding contribution to soil physics but it is useful nevertheless and will find a place on our bookshelves. It cannot, however, be recommended as an introduction to the subject.

R. K. SCHOFIELD

Agricultural Ecology. G. Azzi. Translated from Italian by E. Fano. Pp. xv + 424, with line and half-tone illustrations. Constable & Co. Ltd., London. 1956. 45s. net.

Girolamo Azzi is Professor of Agricultural Ecology in the University of Perugia—the first occupant of the first chair in this subject: this volume summarizes his work and that of his students. Professor Azzi has collected miscellaneous data on aspects of the environment, e.g. soil, rainfall, temperature—even phases of the moon—and on the growth characteristics of various crops and has shown correlations. The stages of crop development have unfortunately been defined subjectively, for example "in order to avoid errors of evaluation and to render calculation easier, it is found convenient to accept as the date of earing the moment when the field appears to be covered with ears!"

Azzi uses his data to define soil and meteorological "equivalents" for various crop plants. These are the environmental limits for abnormal harvests and represent a new and perhaps useful concept in phenology.

Part of the book is concerned with statistical methods and the author goes to some lengths to explain what is meant by correlation coefficients and factorial design of experiments. This emphasis is

praiseworthy, for advances in agronomy depend largely on experiments on the interaction of factors, and only statistical methods, in particular experiments of factorial design, allow such interactions to be assessed. But the author fails to explain the importance of randomization; he gives the impression that correlation proves causation, and he does not discuss tests of significance. The parts of the book devoted to statistics make dangerous reading for the uninitiated.

This volume is not a general textbook of agricultural ecology, rather it is a monograph of the work of one Italian school. Seventy-two per cent. of the references are to Italian literature and the author's approach appears therefore both national and narrow. The book is a typical product of an academic isolation which is perhaps desirable to the philosopher and the mystic but brings few rewards to the scientist. Apart from brief reference to the work of Lysenko, Vavilov and Garner and Allard, the world literature of agronomy is almost ignored. Outstanding among the omissions are any reference to Klages' "Ecological Crop Geography," a most important contribution to the subject of Professor Azzi's book, and the publications by the American Institute for Crop Ecology of studies by modern techniques and with international collaboration of almost exactly the same problems as concern Professor Azzi.

The translation is awkward and it is hard to believe that the original was so pompous. Despite these many criticisms the author must be congratulated on the immense amount of work he has carried out or directed. It is useful to have a guide

to the agroclimatic factors involved in the cultivation of the olive, grape, fig and date, crops rarely discussed. Perhaps the translation of this book into English will result in an interchange of ideas between Perugia and the rest of the world.

J. L. HARPER

Lucerne Investigations 1944-1953. (*The Grassland Research Institute Memoir No. 1.*) J. O. Green, T. Jones, L. A. Willey *et al.*, with a preface by W. Davies. Pp. 81, with line and half-tone illustrations. The Grassland Research Institute, Hurley. 1955. 10s. net.

This booklet reviews much valuable experimental work on the cultivation and utilization of lucerne, and in his preface to it Dr. Davies, Director of The Grassland Research Institute, hopes that it will serve as a useful record of the agronomic behaviour of the crop. Lucerne has never been grown extensively in Great Britain, possibly because it is difficult to establish and manage, and Dr. Davies suggests that the present acreage (112,000 acres in England and Wales) could be extended with profit over a wide range of soil types, particularly in the drier areas of the country, where it could replace much of the conventional grass and clover leys.

The authors of individual articles are members of the staffs of the Grassland Research Institute and the National Institute of Agricultural Botany. The articles range from a valuable review of current practice in the successful cultivation of the crop to more detailed studies of specific problems. The latter include methods of classification for individual lucerne strains and measurements of their productivity

under different soil and climatic conditions. There is a considerable amount of factual information on the immediate and cumulative effects of winter and summer management of the productivity of lucerne and lucerne-grass leys. The effects of periodicity of cutting on the vigour of various strains in subsequent seasons and on the relationship between the lucerne and its companion grasses are examined in considerable detail. Useful standards are set out for the winter and autumn management of grass and lucerne leys and for the management of crops intended for drying. Other work underlines the importance of selecting the most suitable companion grass for particular soil conditions.

Although lucerne has a high potential yield, a high standard of husbandry is needed to get full advantage from it. These investigations, by emphasizing factors that militate against successful husbandry, set out standards which, if followed, should enable farmers to obtain higher and more consistent production.

Much of the work reviewed is of immediate practical value to farmers and farm advisors, but it may sometimes be difficult for them to extract the important points. Many of the tables are too large to be read in the ordinary way and might have been more suitably placed in an appendix. Short summary tables presenting clearly the important results of the investigations would have been of great help. In spite of these criticisms this publication provides up-to-date account of investigations on the husbandry and management of a crop that is of great potential importance to British agriculture. F. V. WIDDOWSON

ABSTRACTS

CROP PRODUCTION

The value of nitrophosphate for spring sown cereals. G. W. Cooke and F. V. Widdowson, *J. agric. Sci.* 1956, 47, 112-15.

Over the three years 1952-4, 13 experiments were carried out on soils with little easily soluble P_2O_5 on sites where badly managed pasture had been recently ploughed out. Nitrophosphate applied broadcast and drilled was compared with superphosphate + 'Nitro-Chalk' in 8 trials on barley and in 5 on wheat. Fertilizers were applied at rates to supply both N and P_2O_5 at 0.45 cwt./acre. The mean of 13 experiments gave grain yield

increases over the control (supplied with 'Nitro-Chalk' alone) of 3.0 and 4.7 cwt./acre respectively with 'Nitro-Chalk' + superphosphate broadcast and drilled. Corresponding increases with nitrophosphate broadcast and drilled were 1.8 and 4.0 cwt./acre. The nitrophosphate fertilizers appear of little value if broadcast; when combine drilled with seed they are nearly equal to superphosphate for cereals, but it is essential that a high proportion of their phosphorus should be in water-soluble form.

E.M.A.

The responses of sugar-cane to fertilizers. G. E. Hodnett, *Emp. J. exp. Agric.*, 1956, 24, 1-19.

Results of over 1000 experiments in British Colonial and Commonwealth territories since about 1930 are summarized. Responses (cwt. sugar/acre) to nitrogen were observed in all territories and on all soil types; they were usually increased by irrigation; ratoons generally responded more than plant-canes. Ammonium sulphate and 'Nitro-Chalk' were more effective than ammonium nitrate, sodium nitrate or cyanamide. Responses to P and K tended to be smaller than responses to N and more closely associated with soil types; no difference was observed between different phosphatic fertilizers or between sulphate and muriate of potash. Small positive interactions were

found between N and P, and between N and K, but no interaction was found between P and K. Pen manure, by-products and other organic fertilizers frequently gave good responses with considerable residual effects. The sugar percentage was consistently reduced by N but usually increased by K; the effect of P was small and irregular. S.F.A.

Whiptail of early cauliflowers. J. L. Beddall and C. P. Quarrell, *Agriculture, Lond.*, 1956, 63, 114-18.

Preliminary investigations on whiptail carried out by the N.A.A.S. in Worcestershire in 1953-4 show that, in fields receiving the same manurial treatment, symptoms were correlated with increased soil acidity. Further observations were made in 1954-5 on the effects of over-liberal usage of nitrogen as top-dressing. In 1954 plants of variety Snowball were grown on soil dressed with 10 ton farm-yard manure, 10 cwt. fertilizer (7:7:10.5) and 10 cwt. ground limestone, having been watered in pots three weeks prior to planting out with 1 oz. sodium molybdate in 4 gal. water/1500 plants. Three weeks after planting out the cauliflowers were top-dressed with 4 or 8 cwt. 'Nitro-Chalk'/acre. None of the plants developed whiptail. In 1955 the pre-planting treatment with sodium molybdate was given to half the plants (variety Finney) only. The plants were grown in soil treated with 12:12:15 fertilizer at rates of 10, 20 or 30 cwt./acre and top-dressed with 'Nitro-Chalk' at 0, 5 or 10 cwt./acre three weeks after planting out or 10 cwt./acre six weeks after planting out. Whiptail symptoms appeared in plants receiving heavy basal and top-dressings of inorganic fertilizers without molybdenum treatment in early stages of growth. Plants that did receive molybdenum at an early growth stage were able to utilize heavy dressings of fertilizer without harmful effects. E.M.A.

Chemical defoliation of cotton: V. Effects of premature defoliant and desiccant treatments on boll components, fiber properties, germination, and yield of cotton. L. C. Brown and A. H. Hyer, *Agron. J.*, 1956, 48, 50-5.

Acala-44, a commercial variety of Upland cotton, was used to test the effect of two defoliant chemicals, S.E.X. (sodium ethyl xanthate 85%) and Shed-A-Leaf (sodium chlorate 40%), and a crop desiccant, Golden Harvest (PCP 40%). In 1953, S.E.X. and Shed-A-Leaf were applied at 7 lb./acre to either the lower $\frac{2}{3}$ or $\frac{1}{3}$ of the plant at a time when all bolls were im-

mature (under 35 days old). In 1954 the only defoliant chemical used was -Shed-A-Leaf, but Golden Harvest, diluted 1 to 10 with No. 2 diesel fuel and then applied at 8 gal./acre, was also tested, the chemicals being applied to the cotton plant at a time when both mature and immature bolls were showing. Spraying immature bolls had a deleterious effect on cotton: boll size, number of seeds per boll, and the seed and lint indexes were reduced; fibre length was reduced but there was some indication of improvement in its fineness; percentage germination of seed was also affected adversely, as were yields. Defoliant chemicals tested gave satisfactory defoliation in those parts of the plant having mature leaves and bolls at the time of spraying, but little or no defoliation occurred where the crop desiccant had been applied; the leaves dried up within a few days but remained on the stalk. It is stated that the most important factor to be considered in the practice of chemical defoliation of cotton is the maturity of the bolls. E.M.A.

The influence of mineral-rich herbs on the yield and nutritive value of swards. 1. Dry matter production and composition under pasture conditions. B. Thomas, A. Rogerson and R. H. Armstrong, *J. Brit. Grassl. Soc.*, 1956, 11, 10-15.

Four half-acre plots were sown with seed mixture based on that for the Cockle Park three-year ley (16 lb. Scotch perennial ryegrass, 10 lb. English-grown cocksfoot, 4 lb. Scotch timothy, 4 lb. Montgomery late-flowering red clover, 1 lb. Kentish wild white clover) with or without the addition of varying quantities of herb mixture (3 lb. chicory, 6 lb. plantain, 1 lb. yarrow, 5 lb. sainfoin, 4 lb. burnet). The aim was to produce swards with 50, 35 and 20% herb content but botanical analysis showed 22, 14 and 7% establishment of herbs in plots 1, 2, 3 respectively. Total yields of dry matter in lb./acre from five cuts were: Plot 1, 3067; Plot 2, 2976; Plot 3, 3395; Plot 4 (with no sown herbs), 3656, showing that yield from Plot 4 was significantly greater at the 5% level than that from either Plot 1 or Plot 2. There was no significant difference between yields from the different plots with the first two cuts. Inclusion of herbs had no adverse effect on crude fibre or crude protein content or protein digestibility, but significant increases were produced in lignin content and decreases in total sugar content. Inclusion of herbs increased the amounts of the major mineral elements with the exception of sodium and potassium together with the two trace elements copper and cobalt. Owing to unavailability of herbage during the second graz-

ing period no conclusions could be reached on the value of a herb-containing sward for sheep. E.M.A.

The influence of mineral-rich herbs on the yield and nutritive value of swards. 2. Yield, composition, digestibility and feeding value under meadow conditions. B. Thomas, A. Rogerson and R. H. Armstrong, *J. Brit. Grassl. Soc.*, 1956, 11, 82-5.

The effect of increasing the herb content on the feeding value of hay cut from the four experimental plots is discussed. Hay yields in lb./acre were: Plot 1, 3296; Plot 2, 4784; Plot 3, 5992; Plot 4, 5779. Tables show the composition and digestibility of both hay and aftermath and live-weight gains made by guinea pigs fed aftermath. With regard to hay, inclusion of herbs in sward at a level higher than 20% reduced productivity: their presence did not affect crude protein content but caused a decline in crude fibre content, an insignificant increase in lignin and total sugars, and a marked increase in the major elements. Digestibility of crude protein was lowered by the presence of herbs in both hay and aftermath. Feeding value of aftermath, as judged by experiments with guinea pigs, was also adversely affected and crude protein content was lowered by the presence of herbs. Results of these trials do not support previous argument for inclusion of herbs in seeds-mixtures. E.M.A.

The chemical composition and loss of nutrients in silage made with the addition of sodium metabisulphite and halogenated acetate of glycol. J. C. Murdoch, M. C. Holdsworth and M. Wood, *J. Brit. Grassl. Soc.*, 1956, 11, 16-22.

Five trials, mainly small scale, are described in which sodium metabisulphite applied in solid form at rates up to 12 lb./ton on chopped or unchopped herbage and Sovilon (halogenated acetate of glycol) applied as solution at rates 165 g. in 11 gal. water/ton herbage have been used. Four tables are given showing the effect of treatments on chemical composition; pH, organic acid, volatile base content and temperature; volatile acid content; nutrient loss. The addition of sodium metabisulphite in general resulted in well preserved silage and improved quality; it consistently lowered nutrient loss, possibly as a result of lowered fermentation activity; failure of the chemical in two trials has been accounted for by leaching and the difficulty experienced in mixing a small quantity of preservative in solid form with large quantities of herbage. Solivon, even

at rates higher than recommended, did not affect appreciably the quality of the silage. E.M.A.

CROP PROTECTION

The systemic action of benzene hexachloride in plants: quantitative measurements. F. R. Bradbury and W. O. Whitaker, *J. Sci. Fd Agric.*, 1956, 7, 248-53.

The take-up of γ -BHC by a variety of seeds and by wheat seedlings showed that the process had similarities with the absorption of γ -BHC by insects. The quantity of insecticide absorbed by seeds from the saturated vapour in 6 weeks varied from 31 $\mu\text{g./g.}$ in wheat to 128 $\mu\text{g./g.}$ in linseed. Wheat seedlings grown in an aqueous solution of γ -BHC removed up to 100 $\mu\text{g./g.}$ of the toxicant in 7 days, but increasing amounts of the insecticide were lost from the plants by volatilization as the experiments proceeded. All the insecticide applied as a seed dressing may be absorbed, and the main effects of γ -BHC dressings are thought to be probably of a systemic nature. D.L.

Armi nuove e potenti per la lotta contro la mosca delle olive. (New and powerful weapons for the fight against the olive fruit fly.) G. Pellegrini, *Ital. agric.*, 1955, 92, 747-54.

Although parathion is effective in controlling the olive fruit fly, *Dacus oleae*, there has been a need for an equally effective insecticide that is less hazardous in use, especially with regard to the question of residues in the expressed oil. Field trials in Italy with N-monoisopropylamide of o,o-diethyldithiophosphorylactic acid (I), N-monoethylamide of o,o-dimethyldithiophosphorylactic acid (II), and the N-monoisopropylamide of the same acid (III) have shown their ratio of activity against *D. oleae* in olive fruit to be 7.4, 10.0 and 10.0 respectively, compared with 1.0 for parathion. Total kills of larvae were obtained within 3 days, using dust formulations of I 1%, II 0.5%, and III 0.1%; parathion 3% gave 90% kill after 8 days. In later tests it was found that a dust formulation of II 0.5%, present on the fruit for 4 hours, gave total control of larvae within 2 days. All three compounds gave 100% kills of adult *D. oleae* within 24 hours, and they gave 100% control of larvae hatching from eggs 26 days after fruit had been treated with aqueous formulations at 0.03%. The persistence of I was further shown in a field test from which 4000 olives were sampled: 2 live

larvae were present 100 days after treatment with a solution of I at 0.06%, whereas 128 were present after spraying with parathion 0.08% and 140 in the controls. The acute oral toxicities of the compounds to mice are 2.3, 10 and 22 times lower than that of parathion. It is suggested that the use of these materials would afford greater safety in application and in the use of olive oil, fewer applications would be required, and dust formulations would overcome application difficulties in areas where water is scarce. D.L.

Griseofulvin and club-root of cabbages. C. Potter, *Rep. Rothamst. exp. Sta.*, 1955, 129-30.

Griseofulvin added to the soil at the time of inoculation with the club-root organism, *Plasmidiophora brassicae*, inhibited the development of club-root symptoms on cabbage plants for at least 6 weeks. The highest concentration of griseofulvin gave the greatest reduction in club size, and at all dosage levels griseofulvin was most effective against the lowest concentration of inoculum. Infected roots increased less in size when griseofulvin was later added to the soil. D.L.

Control of coffee berry disease in Kenya. K. R. Bock and R. W. Rayner, *Nature, Lond.*, 1956, 178, 217-18.

Early in 1955 the effects of a wide range of fungicides were assessed against coffee berry disease, attributed to *Colletotrichum coffeanum*. Only Perenox, applied fortnightly throughout the season, and Verdasan, applied 5 times at monthly intervals during the rainy seasons, gave effective control of the disease. Perenox used at the same frequency as Verdasan was not effective. In trials conducted in 1951, no material (including Perenox) showed promise. Calcium sulphamate as low as 1% was highly phytotoxic to coffee. Preliminary trials with griseofulvin at 880 p.p.m. gave results comparable with those given by Verdasan. D.L.

Laboratoriumonderzoek over de biologie en de bestrijding van *Venturia inaequalis* (Cke) Wint. (Laboratory investigations into the biology and control of *Venturia inaequalis* (Cke) Wint.) (With English summary.) G. S. Roosje, *Meded. Dir. Tuinb.*, 1955, 18, 139-51.

In trials over 2 years with artificial inoculations with the apple scab fungus, *Venturia inaequalis*, it was established that ascospore infection succeeds at 17 to 20°C

if leaves have been wet for more than 8 hours. At least this period of wetness was needed for successful inoculation with conidia. The incubation period before the appearance of lesions was 9-11 days. On grafted trees in pots, scab control was obtained with the following fungicides when used within the period stated after leaves had been wetted: AAventa 0.07%, 40 to 48 hours; Nirit 45 (dinitrorhodane benzene) 0.2%, 21 to 27 hours; captan 0.3%, less than 26½ hours; ziram 0.2%, less than 21½ hours; and thiram 0.2%, less than 21½ hours. In nursery trials, effective scab control on shoots of E.M. II stocks was given by AAventa 0.1% applied within 72 hours of wetting, and by thiram 0.125% applied within 17 hours. When various materials were used against scab lesions that had been visible for 2 weeks, the following order of decreasing efficiency was found: AAventa 0.1%, Nirit 45 0.2%, ziram 0.2% = captan 0.3%. It was also observed that, although inoculation with conidia obtained from a different variety of apple could result in the formation of typical scab lesions, it was not uncommon for no infection to occur or for the disease to manifest itself as chlorotic spots instead of scabs. D.L.

The effects of certain herbicides on plant pathogens. W. E. Chappell and L. I. Miller, *Plant Dis. Repr.*, 1956, 40, 52-6.

American weed control studies in 1954 indicated that groundnut plants in herbicide-treated areas were often larger and more vigorous than plants in untreated areas. Laboratory studies showed that sodium pentachlorophenate and dinitro-o-sec-butyl phenol (DN) were effective against a wide range of pathogenic fungi, and the former chemical was also capable of killing the sting nematode (*Belonolaimus gracilis*) at a strength of 1 p.p.m. in 48 hours. CIPC, CDAA, CDEA, and CDEC prevented the growth of some, but not all, of the organisms tested. Records were kept in 1955 of the incidence of disease in herbicide-treated plants. It was not proved that the herbicides acted as fungicides or nematocides in the field, but Cercospora leafspot was certainly checked in treated fields by DN at 12 lb./acre and by sodium pentachlorophenate at 30 lb./acre. DN at 9 lb./acre reduced the incidence of infection by *Sclerotium rolfsii* by about 60%. D.L.

Recent Research Work. MCPB. L. J. Matthews, *N.Z. J. Agric.*, 1956, 92, 472.

Results are given of experimental work carried out in New Zealand comparing

MCPB (2, methyl-4, chlorophenoxybutric acid) and 2,4-DB (2,4-dichlorophenoxybutric acid) formulated as salts and esters with standard MCPA and 2,4-D preparations on clover species, lucerne, peas and new pastures. MCPB was found to be the most selective material against clovers: rates up to 1 lb./acre caused no injury to seedling clover and 2 lb./acre did not check white, subterranean or red clover in advanced stages of growth. Severe injury to lucerne was caused by MCPB at 1 lb./acre and its use in this crop cannot be recommended; 2,4-DB proved less toxic to lucerne. MCPB appeared a most valuable weed-killer for use in peas, and in new pastures it could be used for controlling weeds in seedling stage of growth when use of phenoxyacetic acid compounds was ruled out because of injury to clovers. Lists of weeds susceptible to MCPB at rates of 1 and 2 lb./acre are given. Weeds resistant to MCPB were rushes, mature docks, cape weed, yarrow, chickweed.

E.M.A.

Wetting ability of aqueous herbicidal sprays as a factor influencing stands of alfalfa seedlings. H. P. Dorschner and K. P. Buchholtz, *Agron. J.*, 1956, **48**, 59-63.

The wetting ability of a droplet of spray solution is a numerical expression termed the spreading coefficient. Laboratory experiments were carried out to determine both the contact angles and the spreading coefficients of three formulations of 2,4-D and of the triethanolamine salts of different phenoxyacetic acids. Using lucerne as a test plant in statistically-designed experiments, the butyl ester, triethanolamine, and sodium salts of 2,4-D (2,4-DE; 2,4-DA; 2,4-DNa) without and with a wetting agent (Tween 20) to equalize the spreading coefficient of the different solutions, were sprayed at rates of 0.25, 0.5 and 1.0 lb. in 20 gal. water/acre. 2,4-DE (the best wetter) was the most toxic; 2,4-DA (the poorest wetter) was the least toxic; 2,4-DNa was intermediate both in wetting ability and toxicity. When the spreading coefficients of 2,4-DA and 2,4-DNa were raised to equal that of 2,4-DE their toxicity to lucerne, although increased, never equalled that of 2,4-DE. Further trials investigated the correlation between wetting ability and toxicity of the triethanolamine salts of 2,4-D, MCPA, 2,4,5-T, 3,4-D, 2,5-D and chlorophenoxyacetic acid (CPA). No close association was found between spreading coefficient and toxicity when different phenoxyacetic acids were studied. Shading appeared to increase the wetting of the leaves and the toxicity of the various chemicals. Wetting

ability of a herbicidal solution is a significant factor in determining the toxicity of preparations of any one compound but does not explain differences existing between different chemicals.

E.M.A.

Responses of the rice plant to different formulations and methods of application of 2,4-D, MCP and 2,4,5-T. P. B. Kaufman and A. S. Crafts, *Hilgardia*, 1956, **24**, 411-53.

The effect on rice and on aquatic weeds of aqueous and pelleted formulations of 2,4-D, MCPA and 2,4,5-T under greenhouse conditions are compared. Applied to the water in aqueous solutions, the most deleterious effects on the rice plants occurred with all three chemicals when the rice seed was sown on top of the soil as contrasted with being drilled into the soil, when the rice was treated at early stages of growth, and when the dosage was high. Damage was greatest with 2,4-D. Treatments with pellets caused intense aberrations in rice and weeds when the plants were young, when dosage was high, and when 2,4-D was used. MCPA was less injurious to rice yet it killed aquatic weeds. The 2,4,5-T treatments were ineffective against weeds. At equivalent dosages pellets were more selective than were aqueous solutions and, under the conditions of these experiments, controlled aquatic weeds without injury to the rice.

M.M.W.

The crop toxicity period of CMU in a sandy clay loam soil. L. L. Danielson, *Weeds*, 1956, **4**, 255-63.

This 24-month study, carried out on a moderately well drained sandy clay loam soil of pH 5.6, made use of glazed drainage tiles set into a field plot to simulate field conditions. Duration of the phytotoxic period of CMU (3-p-chlorophenyl-1,1-dimethyl urea) was determined by the effect of rates of application up to 50 lb./acre, mixed with the top 5 in. of soil, on the growth of sweet corn, snap beans, spinach and kale. Pre-emergence applications of 1 lb./acre CMU which control annual grasses and broad-leaved weeds did not affect snap beans, sweet corn or spinach appreciably. CMU at 1 or 2 lb./acre did not remain in the soil in sufficient strength from one season to the next to be toxic to the crops, and the somewhat surprising dissipation of the 50 lb./acre application in the two-year period is thought to be hastened by mixing the chemical into the top soil. Irrigation did not affect the detoxification rate of CMU.

E.M.A.

Leaching and decomposition of 2,2-dichloropropionic acid in several Iowa soils. J. T. Holstun and W. E. Loomis, *Weeds*, 1956, **4**, 205-17.

Laboratory tests on leaching 2,2-dichloropropionic acid (dalapon) were carried out on nine soil types, collected from the field, air dried and prepared in soil columns 7 in. high of 2.6 in. diameter and treated with the equivalent of 24 lb./acre dalapon. After leaching with 1.5 in. water the mobility of the chemical was indicated by growth responses of soya beans grown in sections of the soil columns. Dalapon showed a high degree of mobility in many soil types and this was decreased by the addition of manure but increased by sand. Millet seedling growth indicated the decomposition rate of dalapon in soils subjected to modifications of temperature, moisture and pH and also partial sterilization. From these experiments it appears that decomposition of dalapon is primarily a function of unspecified soil micro-organisms: other factors influencing decomposition rate act indirectly by affecting these organisms. Low soil moisture, temperatures below the range 20-25°C, low pH and large additions of organic matter inhibited breakdown of dalapon. The highest rate of decomposition took place in a medium silt loam soil, low in organic matter and limed to pH 6.5. The leaching and decomposition characteristics of dalapon indicate that it has a high potential value for pre-planting control of weeds and that residues will present little hazard of toxic accumulation with continued use at low rates, particularly in warm, humid regions.

E.M.A.

ANIMAL HUSBANDRY

The effect of the grinding and cubing process on the utilization of the energy of dried grass. K. L. Blaxter and N. McC. Graham, *J. agric. Sci.*, 1956, **47**, 207-17.

Determinations were made of the energy retention of six sheep given the same batch of dried grass coarsely chopped, medium ground and cubed, or finely ground and cubed. There were no statistically significant differences in energy retention between the three materials at either of the levels of feeding (600 and 1500 g./24 hr.). Faecal losses of energy were considerably greater when cubes were given, but methane losses and heat losses were much less for cubes than for chopped material. The digestibility of cellulose plus total pentosan fell from 86.6% for 600 g. chopped grass to 56.0% for 1500 g. finely ground and cubed grass; the digestibility

of organic matter other than cellulose and pentosan fell from 78.6% to 75.9%. The differences in faecal loss of energy, methane loss and digestibility reflect the more rapid passage of the cubed material through the digestive tract; the differences in heat production cannot be attributed solely to the additional work of chewing chopped material.

S.F.A.

Effects of supplementing a calf ration with trace minerals, aureomycin and other dietary constituents as measured by growth and feed consumption. W. G. Jones and others, *J. Dairy Sci.*, 1956, 39, 188-95.

Twenty-seven Holstein and Ayrshire calves in groups of 9 were used in the trial. Calves were removed from their dams at birth, fed colostrum for 3 days and whole milk from the 4th day to 4 weeks of age. Milk feeding was gradually reduced and stopped between 6-8 weeks of age. Control Group I was fed a "starter" followed by a "grower" ration, both based on National Research Council's recommendations. Trace mineral supplement fed to Group II supplied in mg./100 lb. body weight: 200 iron, 20 copper, 20 manganese, 10 cobalt, 10 zinc and 0.19 iodine. These minerals were first fed as capsules but later incorporated in the feed. Additional supplement administered to Group III supplied in g./100 lb. body weight: 3 calcium, 2.32 phosphorus, 0.3 magnesium and 2.5 sodium chloride together with vitamins A, B complex, C, D, E and K, and aureomycin. During the first 7 weeks Groups II and III grew at significantly faster rates than calves in Group I. After 8 weeks calves in Group II were larger than those in Group I but their growth rate slowed down at this stage. Calves in Group III continued to grow at a significantly faster rate than those in the other groups and at the end of 24 weeks were decidedly larger. Preliminary data also show that supplements with trace minerals alone or in combination with major minerals and antibiotics control the drop in haemoglobin and red blood cell count which occurs during the first few weeks of a calf's life.

E.M.A.

Antibiotics for the prevention of bloat in cattle grazing ladino clover. B. F. Barrentine, C. B. Shawver and L. M. Williams, *J. Anim. Sci.*, 1956, 15, 440-6.

In this study ladino clover pastures were grazed by steers for periods of 90 minutes both in the mornings and afternoons. The antibiotics tested as bloat preventatives

were: Chlortetracycline (aureomycin), oxytetracycline (terramycin), bacitracin, streptomycin and penicillin, administered orally either in capsule form with a balling gun or in water as a drench. In preliminary studies a dose of 1 g. antibiotic was found to cause diarrhoea and the maximum dosage was set at 300 mg. Penicillin was the only antibiotic that prevented bloat when a single dose of 300 mg. or less was given. Single doses of 25 mg. procaine penicillin controlled bloat in yearling steers; 50 mg. protected them for 1.5-3.0 days. Older steers weighing 900 lb. required 50-75 g. to prevent them from bloat. Potassium penicillin in equivalent amounts was as effective as procaine penicillin for bloat prevention.

E.M.A.

Application of magnesium sulphate to grass silage as a means of preventing hypomagnesaemic tetany. P. McDonald and T. H. Jackson, *Proc. Brit. Soc. Anim. Prod.*, 1955, 109-14.

Since magnesium in the form of oxide or carbonate has an adverse effect on silage, investigation was made of the value of magnesium sulphate added to grass at the time of ensiling as a means of supplementing magnesium in the diet of cattle overwintered on hill or marginal land. Magnesium was incorporated into the herbage of the 3-year-old clover ley either as a spray (28 lb. kieserite in 10 gal. water/acre) 4 days prior to cutting or applied at the time of ensiling (5 lb. kieserite in 4 gal. water/ton fresh herbage). The magnesium contents in D.M. of the silages were: control, 0.19%; Mg sprayed in the field, 0.24%; Mg sprayed at time of ensiling, 0.32%. Considerable amounts of Mg were washed by heavy rain from the herbage sprayed in the field and also leached in the silo. 18 Galloway cattle in groups of 6 were fed the silages from 4th January to 18th March. During January the blood-magnesium level was much lower in animals fed control silage than in those fed magnesium-treated silage but the differences decreased as the feeding of silage progressed. The blood-magnesium content dropped in all groups after all the silage had been eaten and the animals were grazing young grass. Feeding magnesium-treated silage did not enable cattle to build up body reserves of magnesium.

E.M.A.

The relationship between particle size and anthelmintic efficiency of phenothiazine.

J. R. Douglas, N. F. Baker and W. M. Longhurst, *Amer. J. Vet. Res.*, 1956, 17, 318-23.

The authors investigated the anthelmintic property of phenothiazine in grades having average particle sizes of 1-2 μ , 40-50 μ , and particles over 140 μ in diameter. Lambs having an average weight of 50 lb. were used for testing the three products. They were naturally infected with *Ostertagia*, *Trichostrongylus* and *Nematodirus*. Each lamb received a single dose (25 g.) of phenothiazine in gelatine capsule. Faecal worm egg counts were made 2, 4 and 5 days after treatment and on the fifth day all the lambs were killed and their worm contents determined. Particle size was found to have a definite influence upon anthelmintic efficiency, especially in killing effect on the worm. It had less influence in inhibiting egg production. Fine materials had a higher nematocidal activity than coarse, and it is suggested that the most effective preparation of phenothiazine is one containing particles between 1 and 25 μ in size. For prolonged low-dose prophylactic treatment particle size is not important.

J.T.E.

The synergism between Pyrimethamine and Sulphadimethylpyrimidine in the control of *Eimeria tenella*. S. B. Kendall and L. P. Joyner, *J. Comp. Path.*, 1956, 66, 145-50.

Chicks were infected in the usual way with *E. tenella* and from the 48th hour for 4 days they were treated with Sulphamezathine (SM), Pyrimethamine (PM) or both mixed into the mash. Mortality was 100% in untreated chicks. It was 0% from SM 0.05% + PM 0.005%, whereas for the drugs used separately the mortality was 91% for SM 0.05% and 63% for PM 0.005%. Higher concentrations of the drugs in combination, and all concentrations of the drugs used singly, merely delayed deaths without reducing them greatly. Further experiments were carried out to determine the amounts of the two drugs, given in varied proportions, which would save half the chicks (ED50). The ED50 for SM alone was found to be 0.12% and for PM alone 0.012%. There is therefore, very strong potentiation when the drugs are used together. Only about one-fifth as much of each drug is required for the same effect. It is concluded that coccidia are dependent upon p-aminobenzoic acid and upon folic acid for their life. SM interferes with metabolism of the first and PM with that of the second.

J.T.E.

